

Demonstration Enhancement of Pueblo Colorado Wash

Hubbell Trading Post National Historic Site

Grant No. 97-029WPF

FINAL REPORT

Prepared by

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Table of Contents

Executive Summary	i
Site Map	ii
Chapter 1 – Introduction	1
1.1 – Site Background and History	1
1.2 – Statement of the Problem	1
1.3 – Project Goals and Objectives	2
Chapter 2 – Methods of Investigation	5
2.1 – Monitoring	5
2.2 – Channel Geometry	5
2.3 – Structure Measurements	8
Chapter 3 – Results and Discussion	9
3.1 – Channel Response to Treatment	9
3.2 – Summary of Results	13
3.3 – Discussion	13
Chapter 4 – Conclusions and Recommendations	21
4.1 – Project Conclusions	21
4.2 – Recommendations for Future Projects	21
Figures	
Figure 1a: Pueblo Colorado Wash, Permanent Photo Point Locations, Phase 1 Reach	6
Figure 1b: Pueblo Colorado Wash, Permanent Photo Point Locations, Phase 2 Reach	7
Figure 2: Structure Locations and Status, Phase 1, November 1, 2000	10
Figure 3: Structure Locations and Status, Phase 2, November 1, 2000	12
Figure 4: Pueblo Colorado Wash Restoration Project Channel Changes, Phase 1	18
Figure 5: Pueblo Colorado Wash Restoration Project Channel Changes, Phase 2	19
Tables	
Table 1 – Pueblo Colorado Wash Channel Geometry	4
Table 2 – Status of Structures, Phase 1 Reach	14
Table 3 – Status of Structures, Phase 2 Reach	15
Table 4 – Change in Channel Widths, Phase 1 Reach	16
Table 5 – Change in Channel Widths, Phase 2 Reach	17
Appendices	
Appendix I - Photo Point Locations and Views	22
Appendix II - Selected Photographs of Typical Structures and Reaches	23
Appendix III - No Title	24
References	25
Chapter 5 - Water Quality Monitoring	26
Chapter 6 - Water Quantity Monitoring	27
Figure 1-2	29
Figure 3-4	31
Appendix A - Streamflow Data	
Appendix B - Precipitation Record	
Appendix C - Shallow Monitoring Well Data	

Chapter 7 - Exotic Species Removal.....	32
Photographs of Burn Activities	
Chapter 8 - Riparian Revegetation.....	33
Chapter 9 - Community Education and Involvement.....	35
Chapter 10 - Grants, Awards and Publicity.....	36

Executive Summary

Pueblo Colorado Wash at Ganado, Arizona, is a tributary to the Little Colorado River, draining southwesterly from the Fort Defiance Plateau on the Navajo Indian Reservation. The Project Area is located on Hubbell Trading Post National Historic Site. Efforts to restore the wash to a productive riparian area began on a volunteer basis in 1997, and the project was first funded beginning with the 1998 field season under Arizona Water Protection Fund Grant 97-029.

Within the project area the Wash is approximately one-half mile long. Prior to treatment it was grazed year long by trespass livestock, dominated by exotic woody vegetation, mainly Russian Olive and Tamarisk, had been ditched and straightened for flood control purposes, was intermittent in flow, and deeply incised with low sinuosity. The watershed is in poor hydrologic condition with a downward trend due to long-term overgrazing, a proliferation of low standard roads, and replacement of native grasslands by woody shrubs.

A new method of stream channel restoration called "induced meandering" was first applied on a pilot basis at the project area. The purpose of the project was to determine if simple instream structures built by hand from native materials could be used to restore an incised, or gullied, channel to a properly functioning stream with channel width, slope, meander pattern and sinuosity appropriate to the landform. If so, such a method might be useful in treating other gullied river systems throughout the Southwest on a cost-effective basis.

Initial results are promising and the induced meandering method has proven effective in halting channel incision, increasing channel width and sinuosity, reestablishing a flood plain, restoring perennial flow to an intermittent system, and creating favorable substrates for reintroduction of native vegetation. Techniques and results obtained are described in this paper. In brief, channel width doubled from 11 to 23 feet, and thalweg length increased by 467 feet from 2700 to 3167 feet, sinuosity increased, channel slope decreased by 20%, a floodplain has developed and 19 naturally sustaining permanent pools evolved where only 3 were present at the start of the project. The channel is continuing to evolve toward a dynamically stable form with a decreasing need for maintenance and modifications of structures.

The induced meandering method employs two basic structures to modify channel shape and control channel slope. These include deflectors, called baffles and vanes, which deflect stream flow and riffle-weirs which control bed elevation and channel slope. Structures are sized in proportion to the cross sectional area of the channel at bankfull discharge and spaced at proper intervals to induce formation of the desired meander pattern. Vegetation is planted or removed at strategic points to retard or stimulate erosion or deposition of bank materials at desired locations and to expedite channel formation. Various structure designs were tested to develop structures having sufficient shear-stress resistance to withstand flow velocities in excess of bankfull discharge and of the proper shape to initiate aggradation of bed materials in the desired amounts and locations.

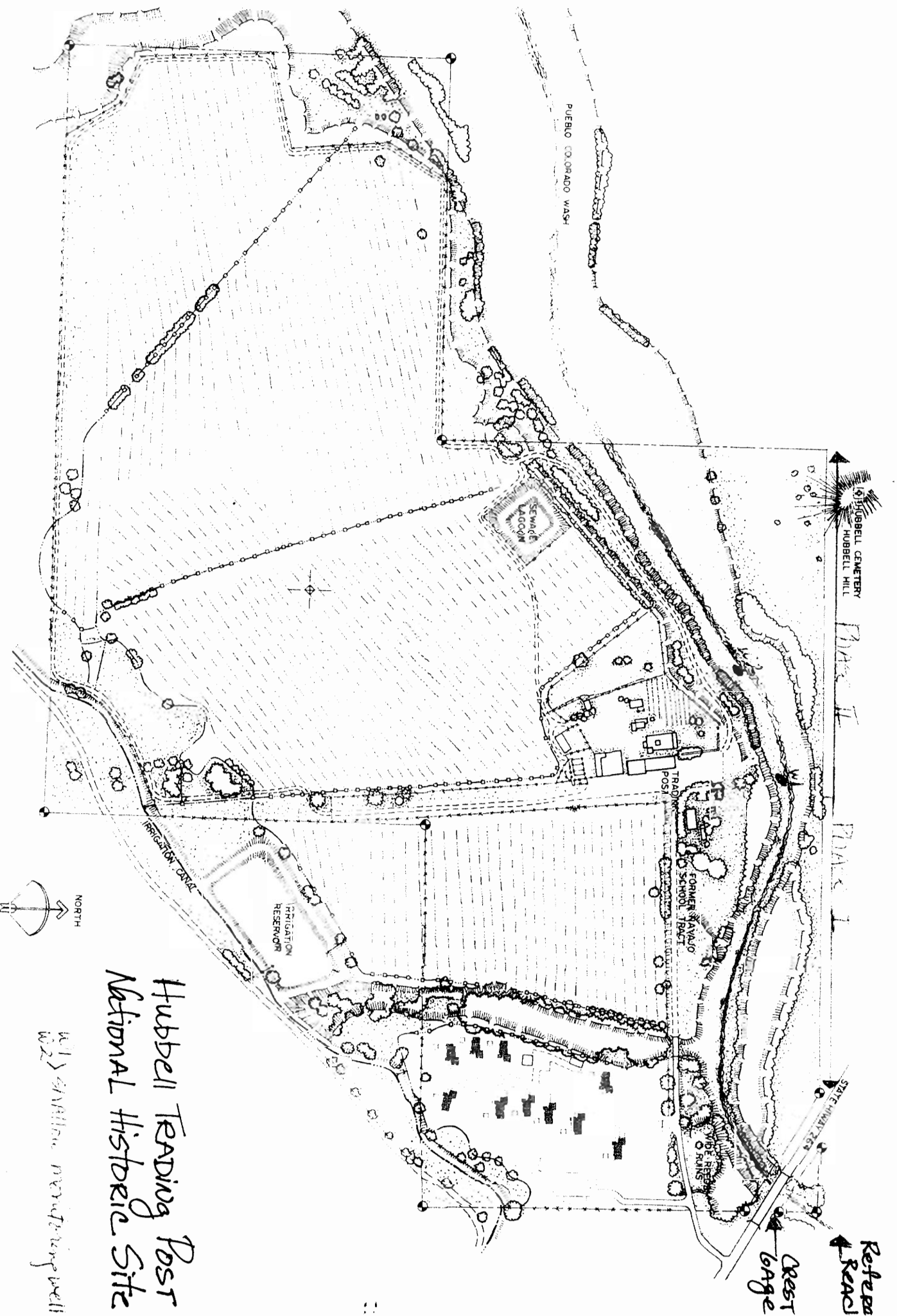
HUBBELL CEMETERY
HUBBELL HILL

PLATE II

PLATE I

Refer
Reel

Rest
Lodge



Hubbell Trading Post
National Historic Site

W1
W2
Saville, Nevada

Chapter 1 – Introduction

1.1 – Site Background and History

Pueblo Colorado Wash at the project location was a deeply incised, highly entrenched, intermittent channel having a low width:depth ratio, moderate slope, and cohesive banks armored by dense stands of Tamarisk and Russian Olive. Year-long grazing prevented establishment of native riparian vegetation. The watershed was in poor hydrologic condition with a downward trend due to long-term overgrazing, the proliferation of improperly drained, low standard roads, increasing suburban development and invasion of native grassland by woody trees and shrubs. These impacts have contributed to increasingly severe and more frequent flood events.

In order to provide flood protection to the Trading Post, the Park Service in 1980 erected a flood wall of gabion baskets and straightened the channel. Bed control structures were installed to prevent downcutting of the channel, but these structures failed soon after installation. As a result the channel dropped, becoming even more incised. The stream side and channel bed were littered with rock, concrete rubble and other debris left over from the channel straightening and construction activities.

Beginning in 1997 the Park Service initiated restoration of the Wash for a variety of reasons including historic, ecologic, esthetic, scenic, recreational and flood control benefits.

During the interim since 1980, the science of fluvial geomorphology has progressed steadily in developing a better understanding of fluvial processes, classifying channel types, predicting channel evolution based on the stream environment and watershed trends, and developing management tools and predictive models. Such advances are well described in the recent literature in such works as *Applied River Morphology* by Dave Rosgen.

River restoration has steadily advanced with new techniques utilizing soft engineering and bioengineering practices in lieu of hard practices such as concrete walled channels, rock and wire baskets, rock mattresses and similar methods. One new approach has been to reconstruct damaged or degraded channels in the form, dimension, pattern and profile that would be expected to occur in that landform setting based upon comparisons with a reference channel or channels. Such reconstructed channels are excavated using heavy equipment, shaped and stabilized using a variety of structures built of natural materials and revegetated using native plant materials. When rebuilt, the channel is expected to function in a normal fashion for the expected stream type with neither excessive degradation nor aggradation of the bed or stream banks through the full expected range of runoff events and flood stages.

While reconstruction has proven highly successful, it relies on the use of heavy equipment which is expensive to operate and imported materials which can be costly to obtain. At Hubbell Trading Post it was decided to experiment with an alternate method using simple, hand-made structures, naturally occurring materials gathered from on-site sources and the power of flowing water to recreate a new channel. The Project would be designed using evolving concepts and principles of river morphology as described in the works of Luna Leopold and Dave Rosgen.

1.2 – Statement of the Problem

Within the boundaries of Hubbell Trading Post National Historic Site, Pueblo Colorado Wash project area was a deeply incised, intermittent channel approximately one-half mile long (2600 feet). The project area was characterized by two reaches: The upper reach was about 1076 feet long, 12 feet wide, incised from 8 to 12 feet and it was still downcutting into cohesive clay banks. Its bankfull discharge was about 180 cubic feet per second (cfs) and it carried a heavy bedload of sand originating from upstream sources. The start of the reach was bounded by a natural waterfall about 8 feet high cut into limestone of the Chinle Formation. It was fed by a spring providing some perennial flow with a discharge rate of 0.2 cfs. This reach had been straightened artificially and had a valley length of 1042 feet (sinuosity 1.04). The upper reach was characterized as a Rosgen G-6 channel type. The lower reach was about 1626 feet long with a valley length of 1436 feet and a sinuosity of 1.13. It was less entrenched with a channel width

of 22 feet, and incised within alternately cohesive clay banks or less cohesive sand and gravel banks. Although not altered by channel excavation, it had been affected by increased discharge velocities and rubble washed downstream from the construction site. The channel was impacted by two utility crossing structures, an abandoned road bridge and a sewer pipeline. The channel displayed four fairly well developed meander apices and streambanks were well armored by woody roots of Tamarisk and Russian Olive. The channel was characterized as Rosgen F-5 channel type and was degrading at mid-length to G-5 due to headcutting action moving upstream from the vicinity of the sewer line crossing.

The overall problem was to stop downcutting in both reaches and to stimulate lateral erosion or extension of the channel banks which would ultimately result in creating sufficient space for an evolving floodplain and a dynamically stable channel condition in which bank erosion would be offset by sediment deposition and bank building processes.

1.3 – Project Goals and Objectives

The project concept was to recreate a dynamically stable channel using induced meandering concepts and technology.

Induced meandering is a new concept for the treatment of incised channels which utilizes the power of running water and the adaptability of native vegetation to reshape and recreate channels in a geomorphologically stable form. In-stream structures are used to redirect channel-shaping flows and control channel slope while streambank vegetation is manipulated to either promote or retard streambank erosion or deposition, thereby accelerating natural channel forming processes that eventually lead to the evolution of a dynamically stable channel. Induced meandering is an alternative to channel reconstruction using mechanized equipment, to “hard” engineering practices, and to the use of check dams in stream channels that do not evolve as step pool systems. Each method has its own advantages and limitations, a discussion of which is not the purpose of this report. The principal limitations of induced meandering are the time and uncertainty of relying upon future discharge events to reshape the channel as planned and having the confidence and patience to await predicted results.

Incised channels include Rosgen G and F channel types entrenched within alluvial valleys where the expected mature channel might be a B, C or E type. Under the Rosgen classification system, G and F channels are highly entrenched types having no floodplain, but B, C and E channels have floodplains of increasing widths and decreasing slope gradients where flood energies are dissipated and deposited sediments sustain diverse riparian plant communities and an alluvial water table.

Within the project area specially designed deflectors, called baffles and vanes, were installed in the appropriate configurations and spacing intervals to induce the stream to meander back and forth across the incised channel generating a sine wave of the proper wavelength (meander length) and amplitude (belt width) to create a dynamically stable channel appropriate to the landform.

Baffles are designed to deflect stream current toward the opposite bank and to be readily overtopped by flood flows exceeding bankfull stage. Deflection of the current accelerates flow velocities and directs stream energy toward the base of the opposite bank. The resulting increase in shear stress erodes the channel bank and undercuts the opposite bank resulting in formation of a scour pool and subsequent sloughing or collapse of the opposite bank. As the bank collapses, the meander radius increases with a further increase in flow velocities due to increasing centrifugal force. Meanwhile, flow velocities decrease across the surface of the baffle causing bedload and suspended sediments to be deposited upstream, downstream and across the surface of the structure resulting in point bar formation. Keeping the surface of the baffle at or below bankfull elevation promotes streaming flow and minimizes eddying that would scour away potential deposits. As the opposite bank erodes, the center of flow shifts in that direction further reducing velocity over the surface of the baffle and evolving point bar. It is important that the baffle be stout enough to resist the increasing shear forces associated with increasing flood depths and accelerating velocities.

While using deflectors to generate a meandering channel, it was also necessary to control the channel bed elevation and slope gradient. Grade control was accomplished by using riffle-weirs. The assumption was that bank materials eroded or scoured from the receding banks would be deposited and retained on evolving point bars and as riffles downstream from the point of scour. Ultimately the point bars would evolve into a floodplain. Structure design was in keeping with the project philosophy of using only native materials, hand labor, and hand tools for construction.

Riffles or riffle-weirs are designed to control channel bed elevation and pool depth while maintaining a constant channel slope gradient and unobstructed passage of the bedload. Riffle weirs were installed midway between baffles at the meander crossover point and were oriented with the anticipated future course of the channel as it approached the next downstream baffle. Riffle weirs averaged one half mean depth in height and were equal in length to one half bankfull width of the channel. Initially riffle-weirs were constructed solely of rock, but with experience weirs were stiffened with the addition of wooden stakes or pickets to increase resistance to shear stress forces.

The challenge, then, was to determine appropriate channel dimensions, meander pattern and profile for the created channel by modeling an apparently stable reference reach elsewhere in the watershed. A reference reach on Navajo Reservation lands about ¼ mile upstream from the project area was selected, measured and characterized. This site was selected as the only relatively stable reach between the project area and Ganado Dam and Reservoir. From that effort, the following objectives were established: bankfull (channel) width, 28 feet; mean depth, 1.5 feet; width:depth ratio, 18:1; entrenchment ratio, 2.20:1; bed material, sand; sinuosity, 1.3; and Rosgen Channel Type, C-5. Meander length was set at 310 feet (Table 1).

Because the reference reach was incised into sandy banks, but the project channel was incised into cohesive clay banks which would better resist erosion, the meander length was calculated by multiplying channel width by 11. The accepted ratio of meander length to channel width ranges from 10 –14 with the lower multiple used for more cohesive, erosion resistant banks and the larger applied to less cohesive banks. The factor of 11 was arbitrarily selected from the lower end of the range yielding an objective of 310 feet for meander length. The projected channel length was determined by multiplying valley length by sinuosity ($2478 \times 1.3 = 3221$) and rounding off to 3200 feet. The objective for slope gradient was determined by dividing change in elevation by channel length objective ($14 \text{ feet} \div 3200 \text{ feet} = .44$). The project goal was to realize the above objectives within three years, but with no prior experience, in use of the "induced meandering" method, there was no real basis for the time frame.

It was assumed that modest structures would be installed at the start to initiate the meander process and that subsequently the structures would be modified and enlarged in pursuit of project objectives as the channel responded, but the timing, rate and extent of future alterations was not known. Monitoring of structure performance and channel response would provide information needed to trigger structure modification and maintenance actions. It was further assumed that structures would need to be in good repair at the onset of winter in preparation for spring snowmelt runoff and again by late June in preparation for the summer monsoon period.

Table 1 – Pueblo Colorado Wash Channel Geometry
(Response to Treatment, 1998-2000)

Parameter	Management Objective	Pretreatment – June 1998			Post-treatment November 2000		
		Phase 1	Phase 2	Total	Phase 1	Phase 2	Total
Bankfull Width (ft)	28	12	22	--	21	23	--
Mean Depth (ft)	1.5	2	1.5	1.5	1.5	1.5	1.5
Width:Depth	18:1	5:1	15:1	--	14:1	14:1	14:1
Entrenchment Ratio	2.20:1	1.21:1	1.27:1	--	Variable	2.80:1	Variable
Channel Length (ft)	3,200	1,074	1,626	2,700	1,466	1,701	3,167
Valley Length (ft)	2,478	1,042	1,436	2,478	1,042	1,436	2,478
Sinuosity	1.3	1.04	1.13	1.09	1.41	1.18	1.28
Meander Length	310	215	232	225	293	243	263
Channel Slope (%)	0.44	0.62	0.46	0.53	0.41	0.47	0.43
Pebble County (Bed/Bank)	Sand/Clay	Sand/Clay	Sand/Clay	Sand/Clay	Sand/Clay	Sand/Clay	Sand/Clay
Rosgen Channel Type	C-5	G-6	F-5	F-5	F-5?	C-5	C-5

Chapter 2 – Methods of Investigation

2.1 – Monitoring

Because this was a pilot project in the development of induced meandering technology, careful monitoring was an essential aspect of project management. Monitoring included periodic re-measurement of channel dimensions and structure performance as well as photographing and rephotographing a predetermined grid of 13 permanent photo points including 25 views. The AWPf protocol/or photo monitoring plan was closely followed. Photo points were rephotographed semi-annually during late May following spring snowmelt runoff and during late October following the summer monsoon season. Additionally, all structure sites were individually photographed pre-treatment, upon completion, and annually thereafter to monitor performance and maintenance activity. A map of permanent photo point location is included as Figure 1a and Figure 1b. Structure dimensions and channel responses were re-measured semi-annually concurrent with photo monitoring activities. Re-measurement included length, width, height of structures and width of channel at structure sites. Notes were made and kept regarding success or failure of structures relative to shear-stress, flood stage, channel features, revegetation success and other factors with suggestions for improvement. A description of permanent photo point locations and views is included as Appendix I.

In order to document the occurrence and distribution of pools, a sketch map of pool locations was prepared each June during minimum stream flow periods.

Results of findings were correlated with flood stage information gathered at the Crest gage station by Navajo Water Management Branch.

2.2 – Channel Geometry

Channel geometry was characterized in the pre-treatment stage, during 1997 for Phase 1 and 1998 for Phase 2, and re-measured semi-annually as per the approved monitoring plan. The following protocols were observed while conducting measurements:

Channel length was measured to the nearest foot along the thalweg, initially by tape and subsequently by GPS plotting at a scale of 1:2400 using the Trimble Pathfinder Program. Channel length was re-measured annually following the monsoon season.

Channel width or bankfull width was measured to the nearest tenth foot by tape measure stretched at right angles to the channel between left and right bankfull indicator marks at the meander crossover (riffle). Average bankfull width for the reach was determined by averaging all riffle locations; Phase 1, 9; Phase 2, 13.

Mean depth was calculated by multiplying maximum depth, in tenths of a foot, at bankfull stage, by 0.6.

Elevations were measured to nearest 0.1 foot using an assumed datum and benchmark. Elevations were first measured using a hand level and/or a builders transit, however serious errors were noted in year 2000 when elevations were re-measured by laser level. To correct earlier discrepancies, early data have been adjusted to agree with laser measurements.

Meander length to nearest foot was measured along the thalweg between natural meander apices or between artificial apices if established by the installation of deflectors.

Valley length was measured to nearest foot between the start and end of the Phase 1 and Phase 2 reaches and summed as two segments to determine total valley length.

Width:depth ratio was computed by dividing bankfull channel width by mean depth.

Figure 1a: Hubbell Trading Post National Historic Site, Pueblo Colorado Wash, Permanent Photo Point Locations, Phase 1 Reach

(Figure 1a) HUBBELL TRADING POST NATIONAL HISTORIC SITE
 PUEBLO COLORADO WASH, PHASE 1 REACH.
 PERMANENT PHOTO POINT LOCATIONS.

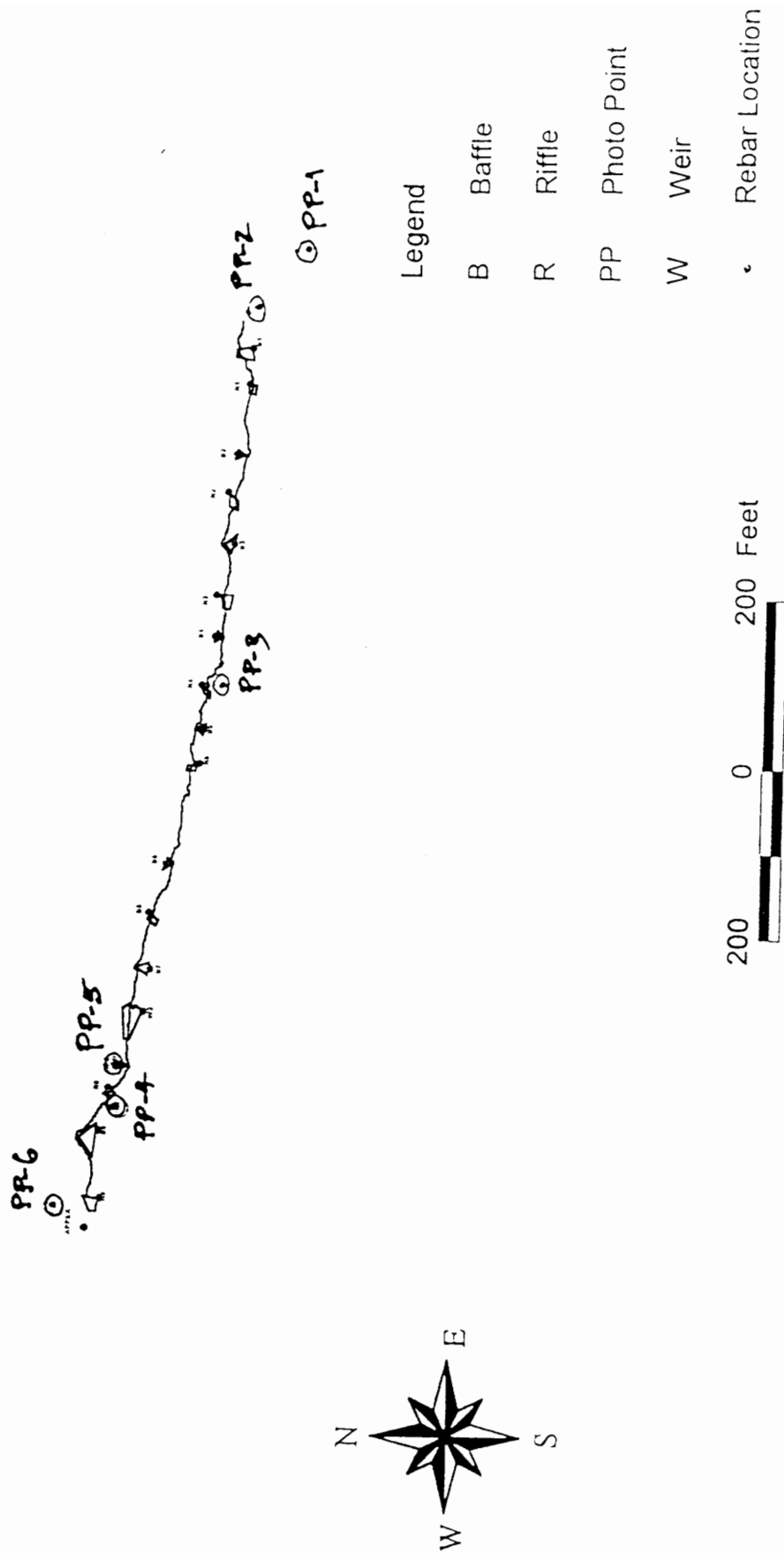
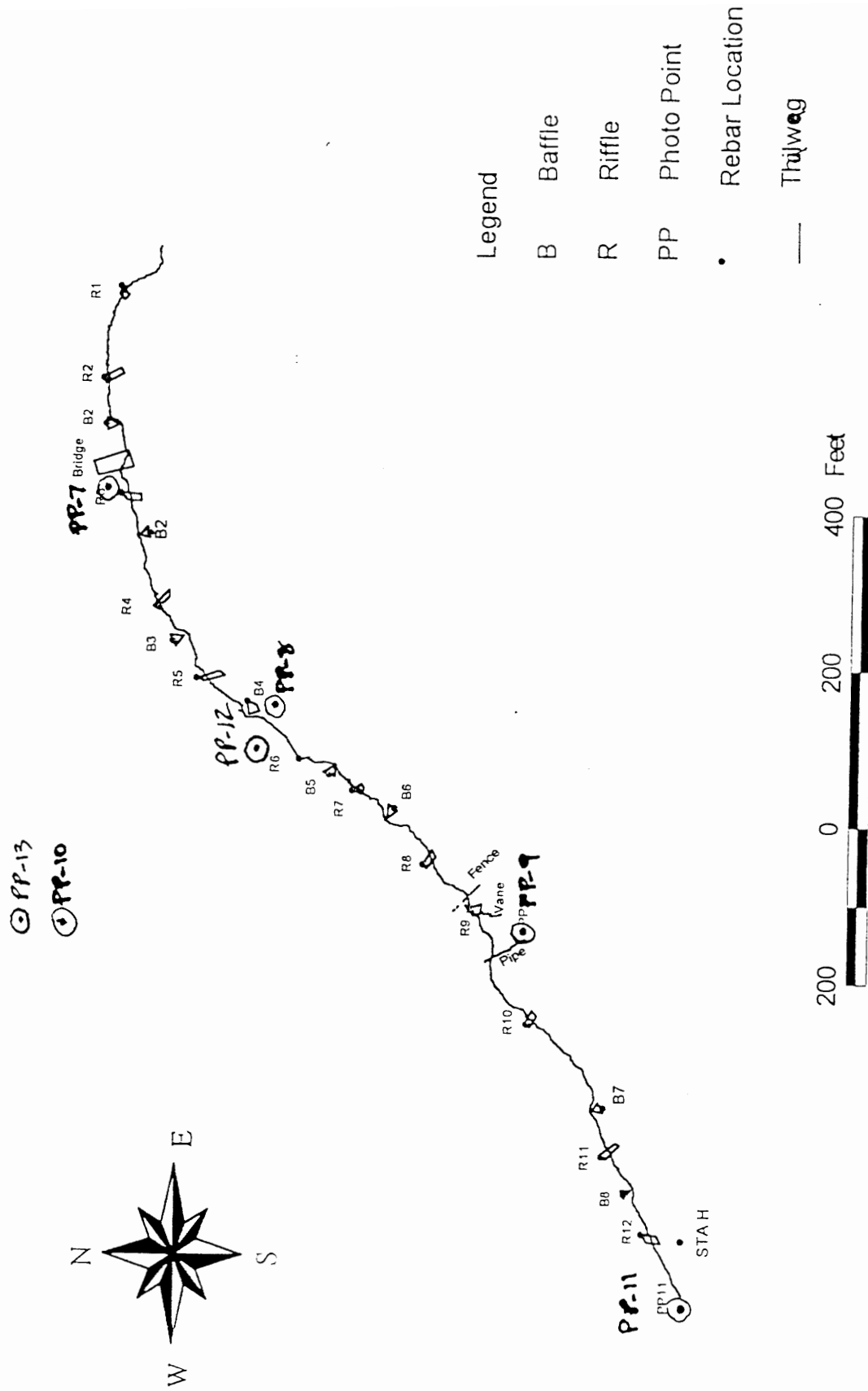


Figure 1b: Hubbell Trading Post National Historic Site, Pueblo Colorado Wash, Permanent Photo Point Locations, Phase 2 Reach

(Figure 1b) HUBBELL TRADING POST NATIONAL HISTORIC SITE
 PUEBLO COLORADO WASH, PHASE 2 REACH.
 PERMANENT PHOTO POINT LOCATIONS.



Entrenchment ratio was determined by doubling maximum depth to establish flood prone width, then dividing flood-prone width by bankfull width.

2.3 – Structure Measurements

A protocol was developed to standardize structure measurements. Photographs of typical structures and sitings appear in Appendix II. Drawings of typical structures and spacing intervals are appended as Appendix III.

Deflectors

Baffle length was measured horizontally to nearest 0.1 foot along the adjacent bank parallel with channel length at bankfull mark.

Baffle width was measured horizontally to nearest 0.1 foot from base to tip parallel with channel width. A rebar pin was set at the bankfull mark to standardize this measurement.

Baffle height was measured to nearest 0.1 foot above thalweg.

Vane length was measured parallel with channel length to the nearest 0.1 foot.

Vane width was measured to nearest 0.1 foot from bankfull mark to upstream tip of structure parallel with channel width.

Vane height was measured to 0.1 foot above thalweg.

Riffle-weirs

Length of riffle-weir was measured to nearest 0.1 foot parallel with channel length.

Width of riffle-weir was measured to nearest 0.1 foot parallel with channel width.

Height of riffle-weir was measured above thalweg to nearest 0.1 foot.

Rosgen Channel Types conform to protocols established in Chapter 5, Applied River Morphology, except that pebble counts were not conducted. Pebble counts were not conducted due to the overwhelming dominance of sand on the bedload composition. Larger particles were introduced artificially, and consisted of cobble or boulder sized materials introduced during the 1980 flood control project or with the present project. Coarser particles of natural origin accumulated only in the lower 400 feet of the Phase 2 Reach.

Chapter 3 – Results and Discussion

3.1 – Channel Response to Treatment

Annual and Cumulative Effects

1997 Phase 1 Initial Treatment

Initial treatment using induced meandering concepts began in June 1997 and was completed in July. Channel dimensions, pattern and profile were modeled after a reference reach located ¼ mile above Hubbell Trading Post boundaries on Navajo Reservation. Based on reference parameters, management objectives were set at: channel width, 28 feet; mean depth, 1.5 feet; width:depth ratio, 18:1; meander length, 310 feet; channel slope, 0.62%; sinuosity, 1.3. Reference channel was a Rosgen C-5 type with a sand bedload but with cohesive clay banks.

Eighteen instream structures were installed during June and July 1997 consisting of 9 Baffles and 9 Riffle-weirs comprising 4.5 meander lengths. Structures were numbered from east to west in a downstream direction with odd number structures on the left bank and even numbered on the right. Phase 1 structure locations are displayed in Figure 2.

No bankfull events occurred during the summer or fall of 1997, but several lesser events occurred initiating channel evolutionary processes. The most significant initial response was a gradual wetting of the toe of the stream banks, especially the left bank due to exposure to pooled water stored behind riffle-weirs. As the wetting spread upward through capillary action, extensive cracks developed along the left bank parallel with the channel opposite Baffles 2 and 4. Some minor sloughing occurred during October 1997, widening the channel by one to two feet in a few places. Simultaneously, small point bars began to form adjacent to Baffles 2, 3, 4, 5, 8 and 9. Some sloughing also occurred opposite Baffle 9. By the time treatment was initiated in 1998 under APWF Contract 97-029, channel width had increased to 12 feet. Initial maintenance during the Fall of 1997 consisted of removing root wads and debris from the channel.

1998 Phase 1 Reach

Snowpack in the Pueblo Colorado Wash watershed during the spring of 1998 was more than 400% of normal. Snowmelt discharge began in February and persisted through April with a discharge on the order of 150 cfs or near bankfull. Significant channel downcutting occurred with two headcuts in evidence. The first proceeded upward from Baffle 3 to Baffle 1, the other from Baffle 9 to Baffle 7 with a depth of 2.5 feet.

Significant bank sloughing occurred opposite Baffles 2, 4 and 9, widening the channel from 1 to 2 feet but root wads within the slumped materials blocked the channel thereby reducing beneficial results and damaging Baffles 2, 3, 4, 5 and 7. It was not possible to remove root wads until snowmelt runoff subsided. Shear forces associated with these floods and eddying around root wads damaged some structures by plucking rocks and rubble from the outer 1-3 feet of the tips of the baffles and scouring channels through some riffles.

As required by Task 5 of AWPG Grant 97-029, all Phase 1 structures were re-measured and evaluated to assess the effects of 1998 snowmelt runoff as the basis for planning maintenance and modifications of Phase 1 structures and the installation of Phase 2 structures (Task 6).

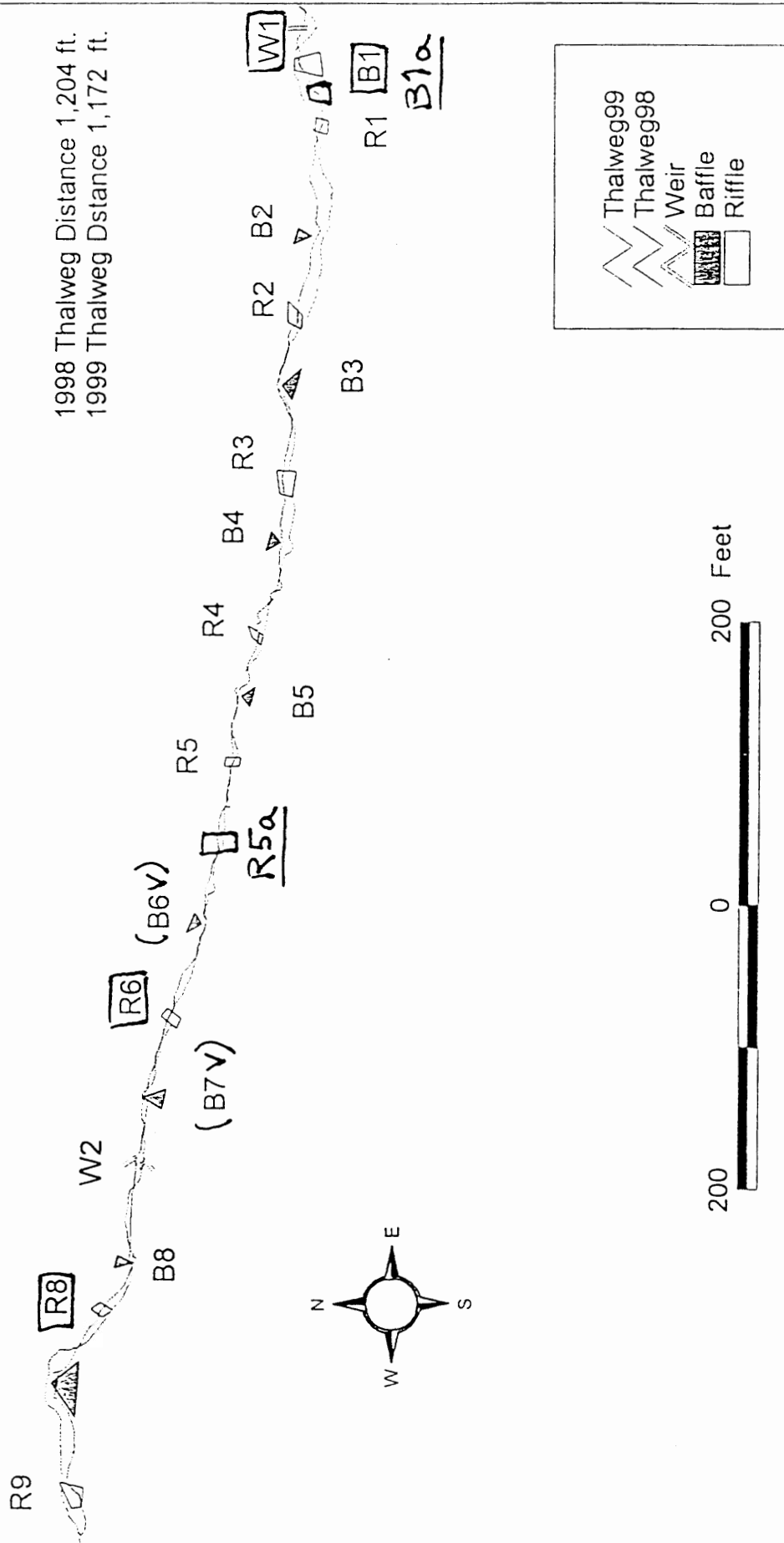
Maintenance and modification of Phase 1 structures began in May 1998 and were completed in June. All structures were modified using rock and concrete rubble from on-site sources. To increase erosion resistance, structures were edged with sod plugs of rooted aquatic herbaceous vegetation, mainly American three square (*Scirpus americana*), which was readily available from the streambank and floodplain. Upon project completion, all structures were photographed and measured to document dimensions. On July 29, 1998, overbank flooding occurred, with a discharge of 800 cfs (5 times bankfull). Although most structures were damaged, channel response was significant.

Figure 2: Structure Locations and Status, Phase 1, November 1, 2000



(Figure 2)
 STRUCTURE LOCATIONS
 AND STATUS, PHASE 1.
 NOVEMBER 1, 2000

LEGEND
 Abandoned... B1
 Added..... B1a
 Converted.... (B6V)



Two important aspects of the channel evolutionary process became apparent at this time: First, the rapid growth of dense Scirpus sod mats on point bars, riffles and lateral bars that increased channel roughness, trapping large quantities of bed load and accelerating bank development on the inside bank and second, the ability of Scirpus to rapidly re-colonize new bed load deposits, and grow up through bedload deposit when covered by sediments.

1998 Phase 2 Reach

Phase 2 structure locations are displayed in Figure 3. Construction in Phase 2 Reach began in June 1998 and was nearly completed in late July when hit by the July 29 flood (800 cfs, or five times bankfull). All rock and rubble structures were damaged; some were destroyed. Baffles constructed of rock and rubble did not have sufficient resistance to withstand shear forces associated with this event. As a result, structures were re-designed and modified to increase their resistance to shear stress. Modifications consisted of adding wooden pickets (stakes) and/or wicker (stakes with interwoven tree boughs) to the margins and interior of baffles and of replacing rock only riffle-weirs with low rock and wicker weirs. Wicker weirs were built to extend from 6 to 8 inches above bed elevation and equal to channel width in length and comprised of 3 to 5 parallel wicker placements. Reconstruction was completed by September and all structures in both reaches were in good repair going into the winter of 1998-99.

1999 Both Reaches

Snowpack was near normal for the winter of 1998-99. Little or no channel degradation occurred during spring snowmelt runoff. All structures received routine maintenance during May and June and were in good repair at the onset of the monsoon season. The condition of all structures was assessed by the consultant and specific maintenance needs or modifications were prescribed and documented by structure. Fourteen pools scoured by snowmelt runoff contained water throughout the low flow period of May and June.

An epic flood occurred August 28, 1999 with a maximum stage at 11 feet where bankfull stage is 1.5 feet (estimated discharge, 9000 cfs). More than half of structures were destroyed or severely damaged. Most structures were replaced or repaired by November 1999. Again maintenance was prescribed and documented by structure. Those not replaced or repaired in Phase 1 Reach included Weir 1, Baffle 1, Baffle 6, Baffle 7, and Weir 2; and in Phase 2 Reach, Baffle 3, Riffle 5, Riffle 6. Significant channel aggradation had occurred in Phase 2 Reach west of Baffle 4, but the channel had degraded between Baffle 2 and Baffle 4 with the subreach evolving from a Rosgen C to a Rosgen G type channel.

Channel length and sinuosity decreased in both reaches and bankfull indicators were obliterated making re-measurement of channel width difficult during the October monitoring cycle.

2000 Both Reaches

Snowpack was less than normal during the winter of 1999-2000 with low snowmelt discharge. Structures were unaffected by snowmelt runoff with only minor repairs required. The decision was made to make major modifications of all structures that had not performed well or had not been replaced following the August 28, 1999 event. As a result, the following adjustments were made to Phase 1 Reach: Weir 1 was abandoned. Baffle 1 was moved 30 feet downstream and labeled B-1a; Baffles 6 and 7 were removed and replaced with Post Vanes and the damaged portion of Weir 2 was replaced with a wicker weir. In Phase 2 Reach, Riffle 4 was moved 30 feet upstream, Riffle 5 was raised, Baffles 2 and 3 were replaced as Post Vanes, Riffle 8 was relocated upstream and replaced by a Post Vane, the 1997 concrete Vane was supplemented with a picket baffle, a new picket baffle was added at Apex 4 and a new Post Vane was installed west of Riffle 12. All structures were in good repair for the year 2000 monsoon season.

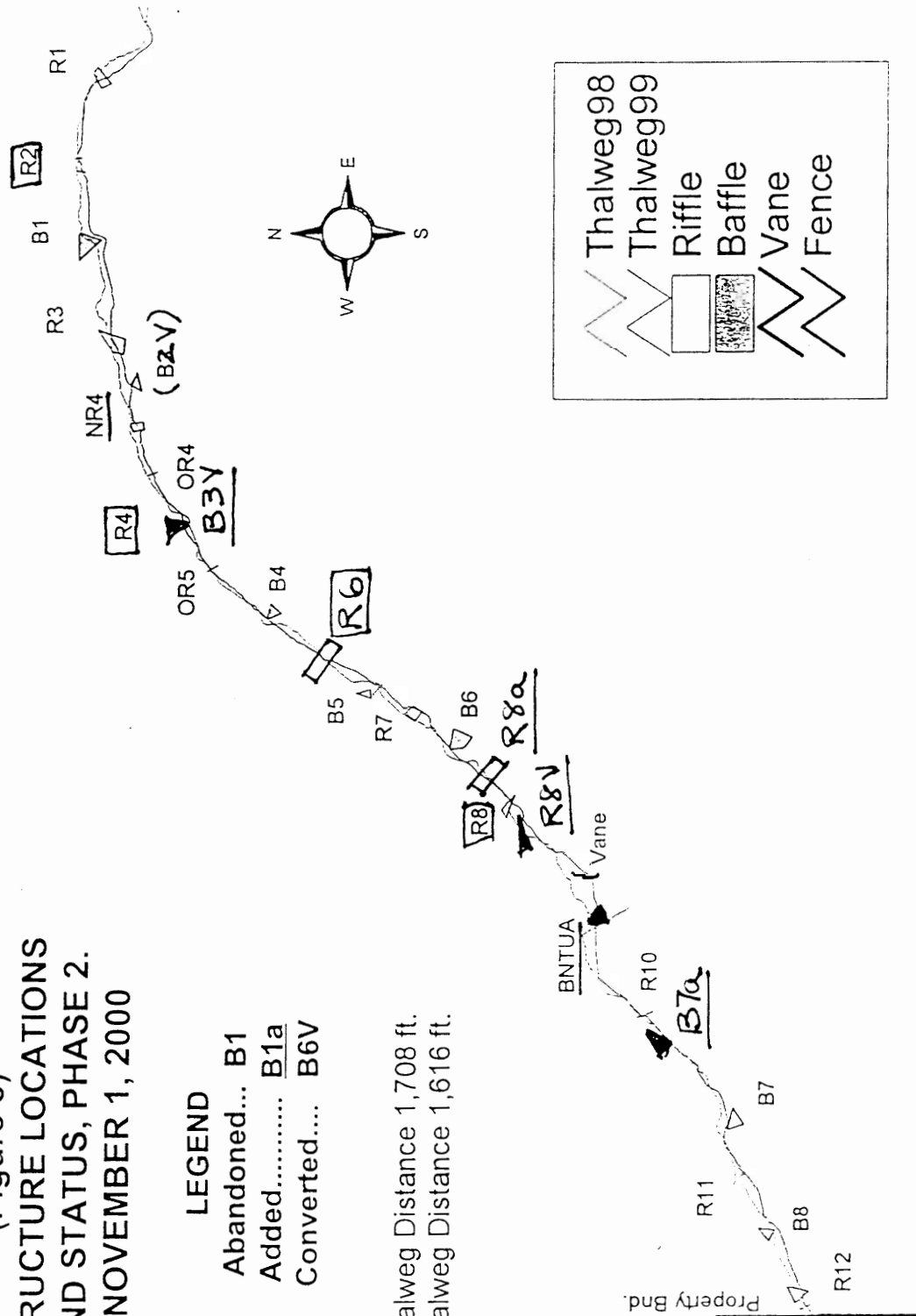
Two overbank events occurred during July 2000. All structures performed well without damage and channel response was significant adding about 300 feet to channel length. All structures were maintained and in good repair prior to the Winter of 2000-2001.

Figure 3: Structure Locations and Status, Phase 2, November 1, 2000

(Figure 3)
 STRUCTURE LOCATIONS
 AND STATUS, PHASE 2.
 NOVEMBER 1, 2000

LEGEND
 Abandoned... B1
 Added..... B1a
 Converted.... B6V

1998 Thalweg Distance 1,708 ft.
 1999 Thalweg Distance 1,616 ft.



The yearly status of all structures, by Reach, as of November 1st annually, is displayed in Table 2 and Table 3.

Changes in structure dimensions with measurements of bankfull channel widths are displayed in Table 4 and Table 5.

3.2 – Summary of Results

Results are displayed in Table 1. In summary, change in channel morphology was more dramatic in the Phase 1 Reach where channel length increased from 1,074 to 1,466 feet (Figure 4), channel width increased from 12 to 21 feet, sinuosity increased from 1.04 to 1.41, channel slope decreased from 0.62 to 0.41% and meander length increased to 293 feet. Change in channel widths in response to structure installations is displayed in Tables 4 and 5. An obvious floodplain up to 35 feet wide has evolved in the upper 400 feet where no floodplain existed prior to treatment. One permanent pool was present in the Phase 1 Reach prior to treatment, but 9 pools were present through the year 2000 low flow period. Flood prone areas are well stocked by vigorous stands of Scirpus and an increasing diversity of other herbaceous riparian species. Overall the Rosgen channel type is F-5 with 2 short subreaches of Type E channel and one residual subreach of G. If the present trend continues, the entire reach is expected to evolve to Type E-5 within the next three years.

Changes in Phase 2 Reach have been more variable and less dramatic. Channel length has increased from 1,628 to 1,701 feet (Figure 5), channel width has increased slightly to 23 feet, sinuosity has increased from 1.13 to 1.18, channel slope has decreased slightly and meander length has increased from 232 to 243 feet. The channel type has evolved from F-5 to C-5, however, a short subreach of Type G channel has evolved between Riffle 3 and Riffle 6 in response to headcutting activity. The number of permanent pools has increased from 2 to 10 and the distribution and abundance of Scirpus and other native riparian vegetation have expanded although less dramatically in the area open to livestock grazing prior to August 1999.

3.3 – Discussion

The cooperators are well pleased with the obvious success of the project especially in the Phase 1 Reach. The rate of change has far exceeded expectations. Although, the project has not been without its problems, adaptive management has resulted in changing the design, construction, and placement of structures and structure types. These modifications have accelerated the rate of channel evolution and proven the effectiveness of the induced meandering concept.

The most significant setback occurred on August 28, 1999 when a summer storm generated a peak discharge of about 9,000 cubic feet per second and water depths of 11 feet above bankfull stage. More than half of in-stream structures were destroyed. Channel straightening and new waves of headcutting activity occurred. Planted cottonwood and willow cuttings were 97% destroyed. Developing beds of Scirpus were buried under deep layers of bedload. Almost all structures had to be rebuilt or relocated and a few were abandoned. However, in hindsight, this storm set the stage for the rapid changes in channel characteristics that evolved during year 2000 and in retrospect proved highly beneficial. Channel response to the August 28 storm was enabled by changes in channel configuration that resulted from the initial in-stream structures. For example, large volumes of bedload with particles up to ½ meter in diameter were deposited on point bars initially formed by the first baffle installations. Additionally, the 1999 storm broadened the evolving floodplain and lowered channel banks which further improved the entrenchment ratio.

The greatest problem encountered in the design and performance of baffles and riffle weirs was their incompetence to withstand the high shear stress associated with high flow velocities at greater than bankfull stage. Initially, structures were built of loosely packed boulders and cobble sized materials arranged in arrowhead shaped form that protruded outward from the bank to mid-channel. Although this type structure could withstand less-than-bankfull events, larger events washed away all but those boulders closest to the bank. This problem was solved by replacing rock baffles with stakes or pickets

Table 2 – Status¹ of Structures, Phase 1 Reach

Site	1997	1998	1999	2000	Comment
W-1	---	R	A	A	Abandoned 8/99
B-1	R	R	A	A	Abandoned 8/99
B-1a	---	---	R	R+P	Installed 10/99
R-1	R	R+W	R	R	
B-2	R	R+W	R+W	R+P	
R-2	R	R+W	R+W	R+W	
B-3	R	R+W	R+P	R+P	
R-3	R	R+W	R+W	R+W	
B-4	R	R+W	R+P	R+P	
R-4	R	R+W	R+W	R+W	
B-5	R	R+P	R+P	R+P	
R-5	R	R	R+W	R+W	
B-6	R	A	A	A	Abandoned 7/98
B-6a	---	R+P	R+P	PV	Installed 7/98, PV 6/00
R-6	R	A	A	A	Abandoned 7/98
B-7	R	R+W	R+P	PV	PV Installed 6/00
W-2	---	R	R	R+W	
B-8	R	R+P	R+P	R+P	
R-8	R	R	A	A	Abandoned 6/99
B-9	R	R+P	R+P	R+P	
R-9	R	R	R	SS	

Notes: W-1 Weir
 B-1 Baffle
 R-1 Riffle-Weir
 R Rock or Rock and Rubble
 R+W Rock and Wicker
 R+P Rock and Pickets
 A Abandoned
 --- Not yet installed
 SS Self-Sustaining
 PV Post Vane

¹ As of November 1 annually

Table 3 – Status of Structures, Phase 2 Reach

Site ¹	1998	1999	2000	Comment
Apex 1	SS	SS	SS	Modified 7/98
R-1	R	R	SS	
Apex 2	SS	SS	SS	
R-2	R	A	A	Abandoned 10/99
B-1	R+W	R+P	R+P	
R-3	R+W	R+W	R+W	
B-2	R+W	R+W	PV	PV 6/00
R-4	R+W	R+W	R+W	Relocated 10/99
B-3	R+P	R+P	PV	PV 6/00
R-5	R	R	R+W	
B-4	R+W	R+W	R+W	
R-6	R	R	SS	
B-5	R	P	P	
R-7	R	R+W	R+W	
B-6	R+W	R+W	R+P	
R-8	R+W	R+W	R+W	Relocated 6/00
Vane	---	---	PV	Installed 6/00
Apex 3	SS	SS	SS	
R-9	R	SS	SS	
Vane	Rub	Rub	P	Installed 6/97
B-NTUA	---	R	R	Installed 10/99
R-10	R	R+W	R+W	
B	---	---	P	Installed 4/00
Apex 4	SS	SS	SS	
B-7	R+W	R+P	R+P	
R-11	R	R	R+W	
B-8	P	P	P	
R-12	R	R	R+W	
Vane			PV	

Rub Concrete Rubble
Other symbols same as Phase 1 Reach

¹ From East to West

Table 4 – Change in Channel Widths, Phase 1 Reach
Channel Width @ BKF (ft)

								Change	
	June 97 ¹	July 97 ²	May 98 ³	July 98 ⁴	Oct 98 ⁵	Nov 99 ⁶	Nov 00	June 97 - Nov 00	Nov 99 - Nov 00
W-1			19.6		22.4	22.4	26.0	---	3.6
B-1 *	11	16.7	19.0	18.8	21.6	21.6	24.0	13.0	2.4
R-1 *	9		13.4		17.9	17.9	25.3	14.3	7.4
B-2 *	14	15.2	19.2	21.1	18.9	18.9	23.0	9.0	4.1
R-2	13		18.5		21.6	18.0	18.5	5.5	0.5
B-3 *	13	15.6	20.1	19.1	20.4	20.5	23.0	10.0	1.5
R-3	13	16.6			20.6	18.0	29.0	16.0	11.0
B-4	12	13.8	15.0	13.9	16.7	17.2	19.0	7.0	1.8
R-4	12		15.7		20.6	21.0	23.0	11.0	2.0
B-5	12	15.0	14.8	15.4	17.8	16.7	19.3	7.3	2.6
R-5	12		18.1		19.0	19.0	21.3	9.3	2.3
Old B-6	9	9.7	10.2		11.1	11.2	11.0	2.0	-0.2
B-6			15.6	14.8	16.1	16.6	17.9	---	1.3
R-6	10		12.0			---	---	---	---
B-7	10	10.3	12.0	21.8	20.4	20.4	20.9	14.4	0.5
W-2	16	16.5	22.0	24.9	25.6	25.6	25.6	9.9	0.0
B-8	12	15.6	18.1	16.7	18.4	18.0	22.6	10.6	4.6
R-8	10		12.6			---	---	---	---
B-9	16	25.0	25.0	26.4	27.3	25.0	29.8	13.8	4.8
R-9			21.0	21.9	22.1	21.0	23.0	---	2.0
Mean							Baf 22.2 Rif 21.3	10.6 11.0	2.6 3.6

¹ Pretreatment

² Post Treatment

³ Post 1998 Spring Runoff

⁴ Post Initial Repairs 1998

⁵ Post 1998 Monsoon Season

⁶ Since 1999 Monsoon Season

* Bank pin lost

Table 5 – Change in Channel Widths, Phase 2 Reach
Channel Width @ BKF^a ft

Feature	May 98 ¹	July 98 ²	Oct 98 ³	Nov 99 ⁴	Nov 00	Change	
						May 98 – Nov 00	Nov 99 – Nov 00
Apex 1 *	10		22.7	20.6	21.0	11.0	0.4
R-1 *	19		23.0	23.0	29.0	10.0	6.0
Apex 2	14		15.3	15.3	15.3	1.3	0.0
R-2	27		29.9	27.0	9.5	-17.5	-17.5
B-1	28	29.1	28.0	28.0	31.7	3.7	3.7
R-3	27		26.0	26.0	24.7	-2.3	-1.3
B-2	21	21.5	22.8	22.8	18.5	-2.5	-4.3
R-4	29		26.0	26.0	8.0	-21.0	-18.0
B-3	28	27.5	22.0	23.6	27.0	-1.0	-3.4
R-5	28		29.0	28.0	15.0	-13.0	-13.0
B-4	23	22.8	20.1	22.1	11.3	-11.7	-10.8
R-6	25		31.0	28.0	24.0	-1.0	-4.0
B-5	18	17.7	23.3	23.5	30.5	11.5	8.0
R-7	14		14.0	14.0	30.0	16.0	16.0
B-6	16	19.6	24.5	25.0	30.0	14.0	5.0
R-8	19		21.0	22.0	25.0	6.0	3.0
R-9	18		21.8	21.8	---	---	---
Apex 3 *	18		Abandoned	---	27.5	9.5	---
R-10	18		Re-established	26.0	18.0	0.0	-8.0
Apex 4	20		Abandoned	---	---	---	---
B-7	23	24.1	30.0	28.0	18.0	-5.0	-10.0
R-11	27		29.1	25.0	29.0	2.0	4.0
B-8	18	20.2	21.8	20.0	20.0	2.0	0.0
R-12	19		22.0	19.0	21.5	2.5	2.5
Mean Baf	21.8 n=8		24.6 n=8		22.7 n=12	4.0	-1.1
Rif	22.5 n=12	22.8	24.8 n=11		22.8 n=11	-1.6	-2.75

^a Apparent BKF, difficult to determine after July 27 flood

¹ Pretreatment

² Post Treatment July 27, 1998. Flood precluded remeasurement of riffles.

³ Post 1998 Monsoon Season and flood repairs

⁴ Post 1999 Monsoon Season

* Bank pin lost

Figure 4: Hubbell Trading Post, Pueblo Colorado Wash Restoration Project Channel Changes, Phase 1

(Figure 4) HUBBELL TRADING POST PUEBLO COLORADO
WASH RESTORATION PROJECT
CHANNEL CHANGES
PHASE 1 REACH

1998 Thalweg distance 1,204 ft.
2000 Thalweg distance 1,466 ft.

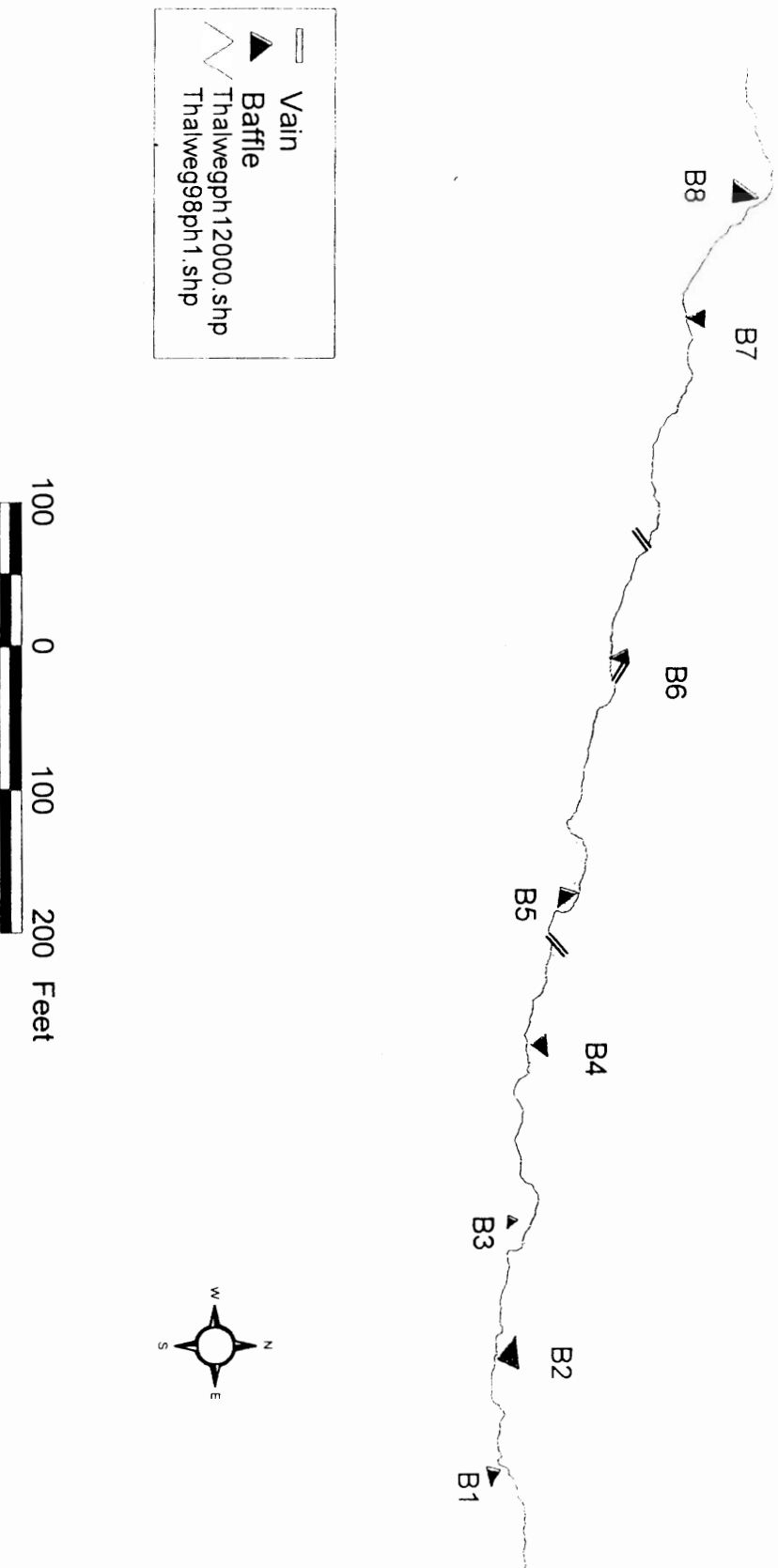
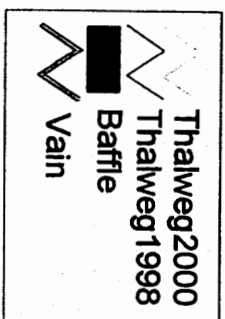


Figure 5: Hubbell Trading Post, Pueblo Colorado Wash Restoration Project Channel Changes, Phase 2

**(Figure 5) HUBBELL TRADING POST PUEBLO COLORADO
WASH RESTORATION PROJECT
CHANNEL CHANGES
PHASE 2 REACH**

1998 Thalweg distance 1708 ft.
2000 Thalweg distance 1701 ft.

100 0 100 200 Feet



driven into the stream bottom on 1 to 2 foot spacing intervals with as many as 100 stakes arrayed in a wedge shaped structure that gradually levered the flow toward the opposite bank rather than turning it abruptly. Only two picket baffles have been destroyed by flood events. Where needed, baffles are easily repaired, modified, or extended by adding additional stakes. Stakes have been cut from Tamarisk, Russian Olive, elm, and cottonwood and average about 2 inches in diameter and 40 inches long.

During the summer of year 2000, seven structures called post or "dead head" vanes were installed for the first time in lieu of baffles (Figure 2). These structures are built using from 14 to 20 posts, 6 to 8 inches in diameter and 7 feet long. The posts are driven into the stream bed at a 30 degree angle to the oncoming flow, extend to mid-channel, and incline downward at 15 degrees from horizontal into the bed. At the bank end, the elevation of the top post is cut to coincide with bankfull level. Vanes have proven very effective at deflecting flows outward toward the opposing bank, however, construction tolerances are sensitive and failure can be expected if the angle with the bank exceeds 30 degrees even by a few degrees.

Finally, a significant problem hindered the construction of riffle-weirs in that, as might be expected, high flows easily eroded weirs fashioned of loosely piled rocks and it was not possible to construct more competent rock weirs using hand labor only. This problem was solved with the development of so-called "wicker-weirs" (Figure 4). Wicker weirs consist of wooden stakes driven into the streambed on two-foot centers with the stems and branches of Tamarisk and Russian Olive saplings up to 1 inch in diameter then being woven between the stakes in the manner of weaving a wicker basket. The wicker weirs are built low, averaging about 6 inches in height above the bed and are constructed as 3 or 4 parallel weirs spread 6 to 10 feet apart with a channel length equal to bankfull width of the channel. This type of structure has proven highly effective at capturing and detaining bedload materials and, if properly built, competent to withstand the highest discharge velocities yet encountered.

With regard to the varying results experienced in the Phase 2 Reach, two factors seem most problematic. First, in the initial design of the project, the spacing intervals between adjacent baffles varied in order to accommodate utility crossings and existing meander features. In contrast, spacing intervals did not vary in the Phase 1 Reach. Secondly, bed and bank materials varied in size and composition in the Phase 2 Reach, but were relatively uniform in Phase 1. These two factors seem to have altered channel response to treatment by interrupting the rhythm of the meander sine wave and thereby frustrating channel forming processes. In subsequent maintenance operations, an effort has been made to correct for this condition by installing additional structures and by varying the size and placement of structures to adjust for differences in bed and bank composition (such as clay versus sand).

It is very possible that had the initial structures been competent to withstand the shear forces associated with the July 29, 1998 and August 28, 1999 storms, project objectives regarding channel length, channel width, sinuosity, entrenchment, and gradient might have been satisfied with the 3-year time frame of the Grant. By the same token, the mature channel type for the valley type and landform described in Rosgen, pages 6-10, is an E-5 channel, not C-5 which is the project objective. It is probable that the channel will evolve to the E-5 Type, not C-5.

Chapter 4 – Conclusions and Recommendations

4.1 – Project Conclusions

Induced meandering is a useful and effective approach to the restoration and rehabilitation of incised channels in the Southwest. The concept of harnessing the energy and power of flood flows to scour new channels and aggrade new floodplains is valid. The Pueblo Colorado Wash experience has been valuable in better defining the problems and considerations which must be addressed in designing an induced meandering project and it has helped to identify the need for a larger variety of structure types and better monitoring methods to cope with different on-the-ground situations.

The obvious shortcoming in the Pueblo Colorado Project was in the inability of initial structures to withstand high shear forces associated with flood flows in excess of bankfull stage. Such events occurred more frequently than expected. Design improvements using pickets, stakes and posts in the design of structures greatly enhanced their competence to withstand high flow velocities. Failure rate has greatly declined with this design change.

Once a meander pattern, meander length, slope gradient and sinuosity have been selected, it is important to adhere to those parameters in channel layout and design. Recurring setbacks and failures at Pueblo Colorado Wash in the Phase 2 Reach resulted from deviations from the original design in order to accommodate various natural and artificial features into the meander pattern. Such deviations resulted in disruptions to the meander wave length that resulted in bank scour or bedload deposition in unwanted locations that were difficult to accommodate or control. Baffles were swept away and riffle-weirs were breached by headcuts where structure locations differed appreciably from initial spacing intervals.

The project was successful in initiating lateral erosion of banks that lead to increased channel widths and an evolving floodplain in the space provided. Meanders are still evolving and expanding as the width increases, but little experience was gained in controlling the outward expansion of the concave bank once target radius was reached. Additional experience in stabilizing the "near bank" against excessive scour is needed within the context of using simple, hand-made structures.

The timing and occurrence of channel forming events is random and unpredictable. Therefore it is essential that all structures be maintained in good repair at all times, but especially in advance of spring snowmelt and summer monsoon seasons. Finally, because of the uncertainties incumbent in the process, it is important that project personnel develop the confidence and patience required to wait out the events which will ultimately result in the expected channel form to evolve and stabilize.

4.2 – Recommendations for Future Projects

Once a project site is selected and before channel design and layout begins, one or more reference reaches should be selected and characterized to carefully describe and characterize the desired channel type and features. Other sources of information, such as regional rating curves, should also be consulted since it is very likely that a model reference reach analogous with the stable or mature form of the channel to be treated may not be available for planning guidance.

Other projects should be planned in a variety of degraded channel situations involving other geological and morphological settings, and in the presence of managed grazing operations to learn more about the effectiveness of induced meandering in the presence of ongoing disturbances.

Monitoring is essential to the success of induced meandering projects and management must be flexible and quick to adapt to new findings with improved methods. Monitoring is also essential to determine when goals have been realized and if project objectives should be amended.

Finally, project success directly relates to the user's knowledge and understanding of fluvial geomorphological principles. An induced meandering endeavor should probably not be undertaken without adequate training on the part of practitioners.

APPENDIX I – Photo Point Locations and Views

The following is a revised list of permanent photo locations and numbers as displayed in Figures 1a and 1b.

1. Top Wide Reed Ruin, east end looking west toward Hubbell Hill, Gabion wall and Baffle 1 in foreground.
2. East end of Phase 1 from top of waterfall, south bank looking downstream across Baffle 1.
3. At Baffle 5, south bank, 3 views: two views looking east toward waterfalls (50mm and 80mm) and two looking west toward Hubbell Hill (50mm and 80mm).
4. At Baffle 8, south bank looking east toward Wide Reed Ruin (50mm).
5. At Baffle 8, north bank, looking west toward Gabion Weir (50mm).
6. Top of Gabion Weir, north bank, 2 views: one east in Phase 1, one west into Phase 2 (50mm).
7. West of old bridge crossing, north bank, views east and west, Phase 2 (50mm).
8. South bank at Phase 2, Baffle 4, 2 views: one east across Riffle 5, one west toward NTUA pipeline crossing (50mm).
9. Top of NTUA pipeline crossing, south bank, 2 views: one east, upstream toward livestock enclosure fence; one west toward park boundary and end of project (50mm).
10. Top of Hubbell Hill, 3 views: one east toward Wide Reed Ruin, 50mm and 80mm, one view south toward NTUA pipeline crossing (50mm), and one view southeast toward the Trading Post.
11. West end of Project. View east toward NTUA pipeline (50mm).
12. North bank at Phase 2, Baffle 4 opposite PP-8; 2 views: one east toward Baffle 3 (35mm) and one west toward Baffles 5 and 6 (50mm).
13. Top of Hubbell Hill at Linda Hubbell gravestone; 1 view (80mm) east toward Phase 1 reach. Site provides a better perspective on channel alignment than PP-10.

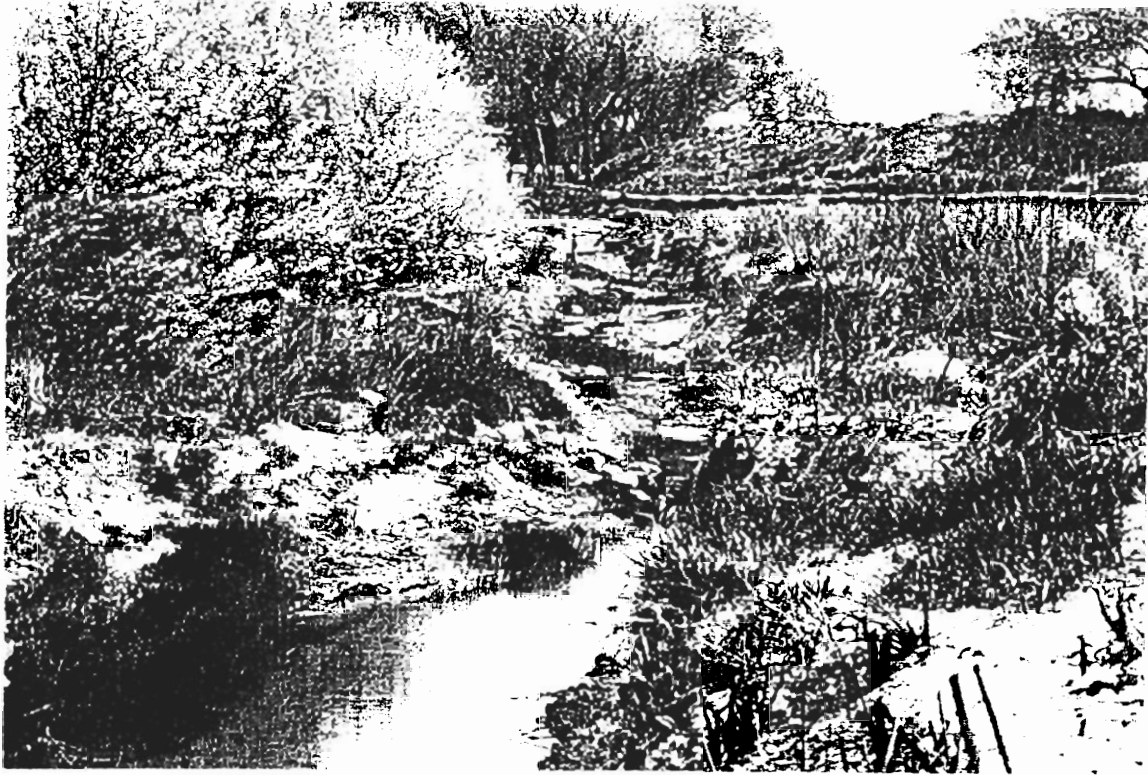
APPENDIX II – Selected Photographs of Typical Structures and Reaches



Pueblo Colorado Wash from permanent photo point number 1, top of Wide Reed Run. View west toward Hubbell Hill. May 23, 2001.



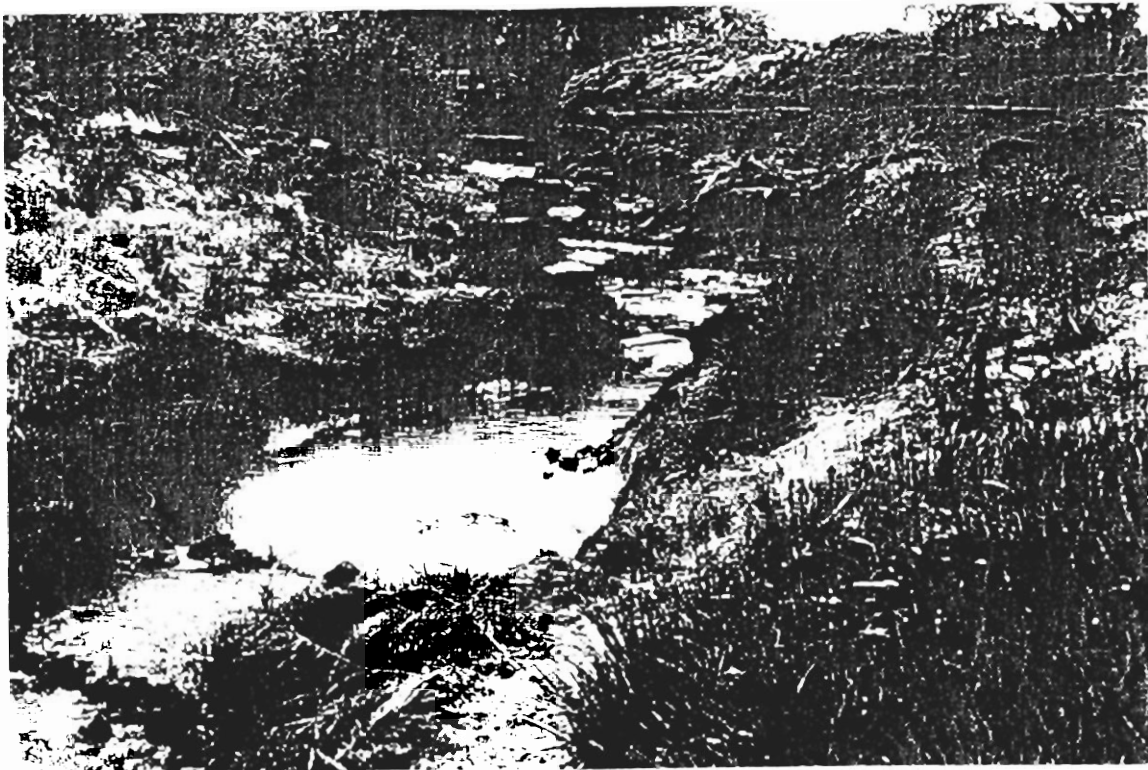
Pueblo Colorado Wash in Cimado. View south from Hubbell Hill. Between east face and Wide Reed Run. May 27, 2001.



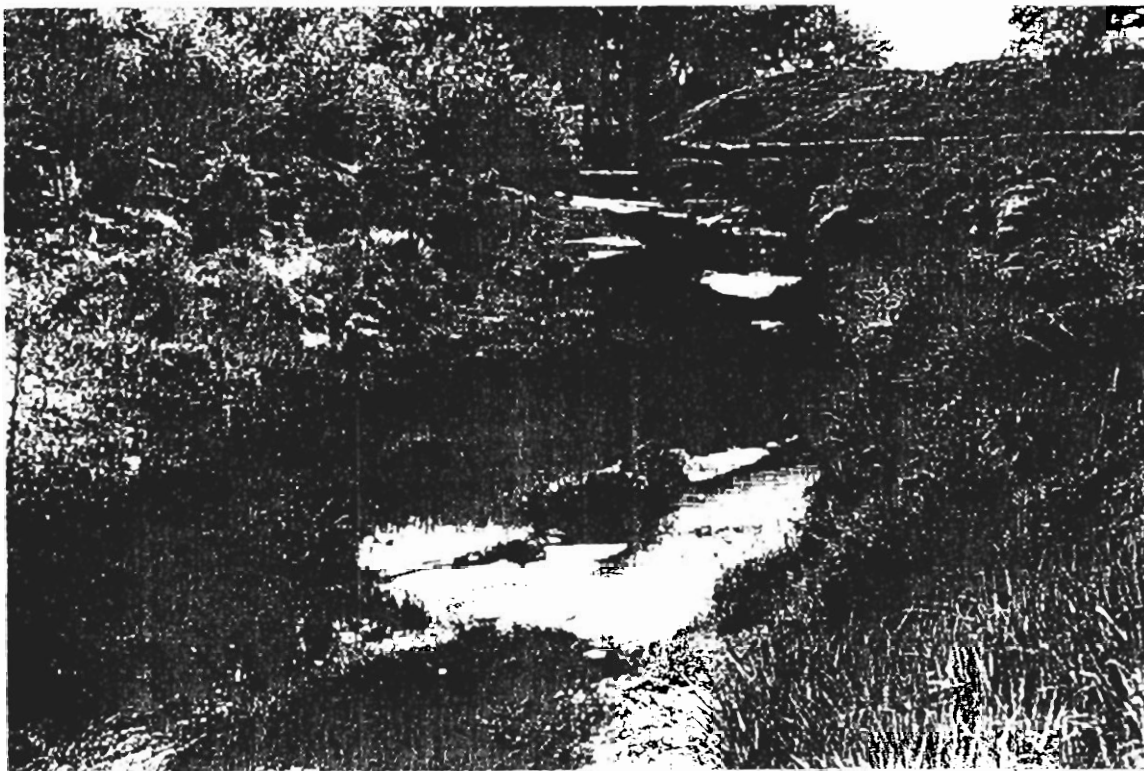
Permanent Photo Point 3x2, view east from top of south bank. Baffle 4, foreground, initially installed by volunteers in June 1997, prior to AWPL Grant 97-029. Note narrow, steep channel, low sinuosity, some early point bar development and bank collapse, May 29, 1998.



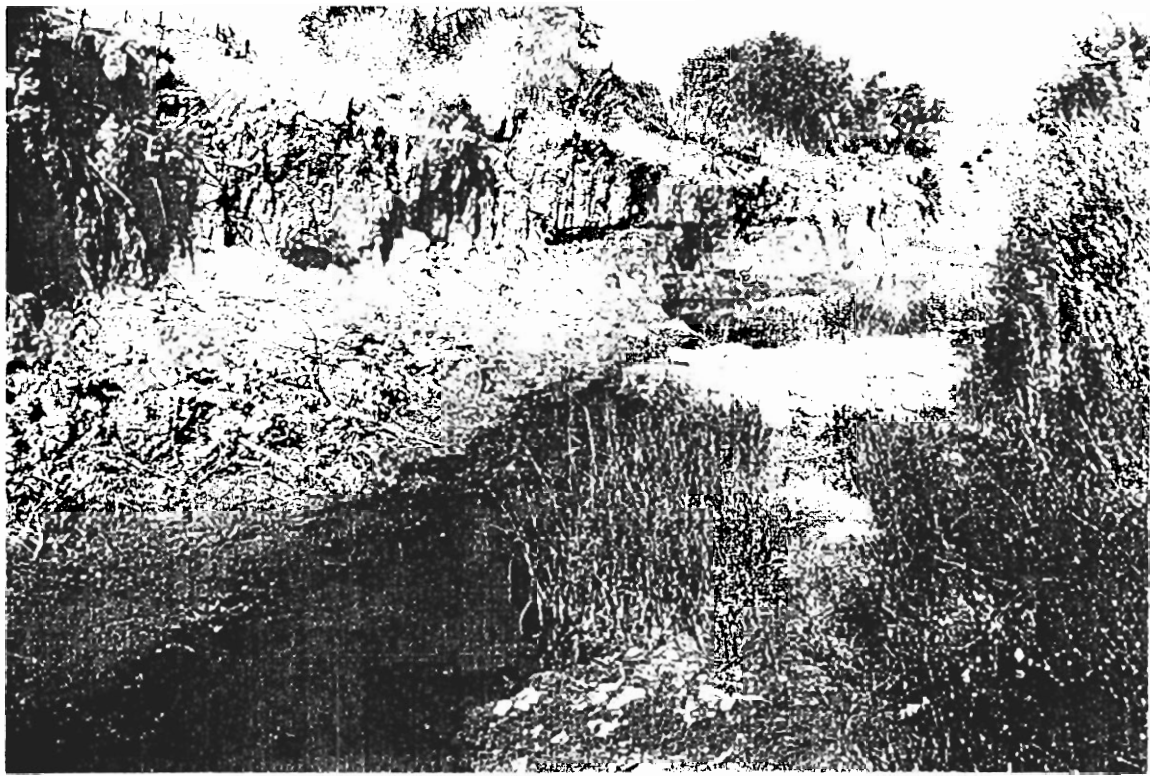
Same view, May 28, 1999. Note expanding point bar at Baffle 4, foreground. Point bar now at Baffle 3 in distance, and bank collapse in right foreground.



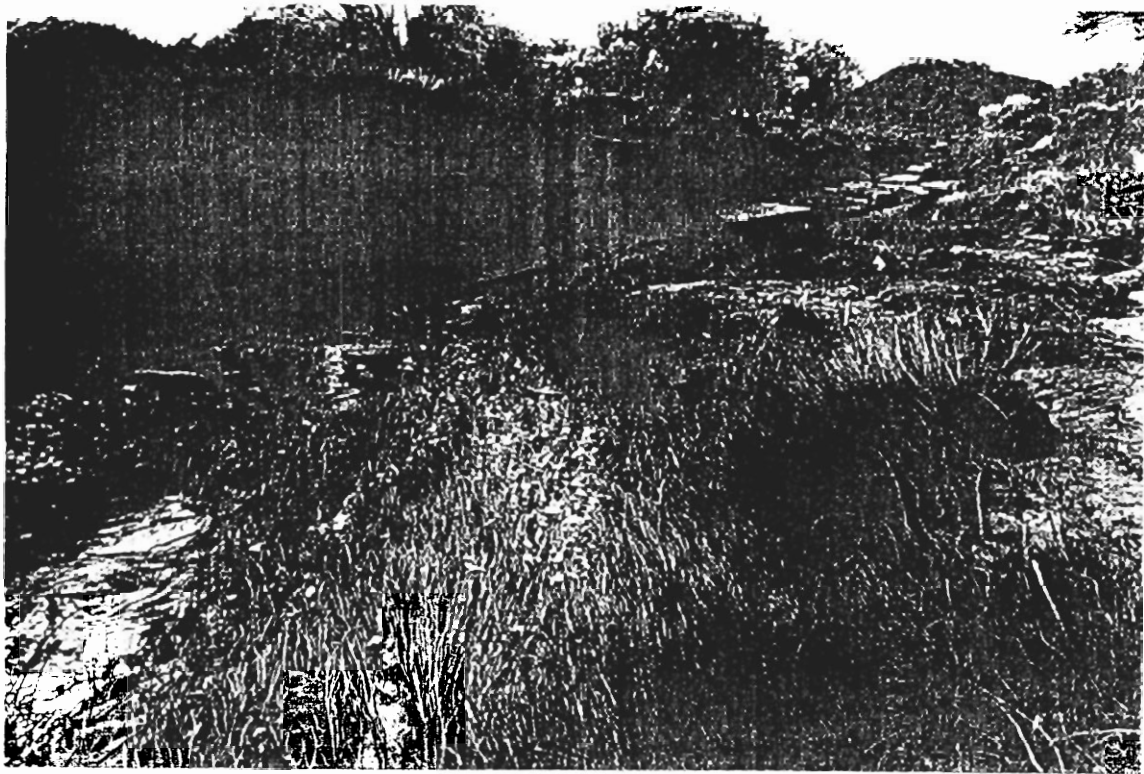
Same view, May 25, 2000. Slight change of camera angle (two feet south, four west) due to bank collapse following 1999 flood. Riffle 4 foreground (Wicker Weir). Battle 4 pickets added, midground. Note point bar expansion and developing flood plain as south bank recedes.



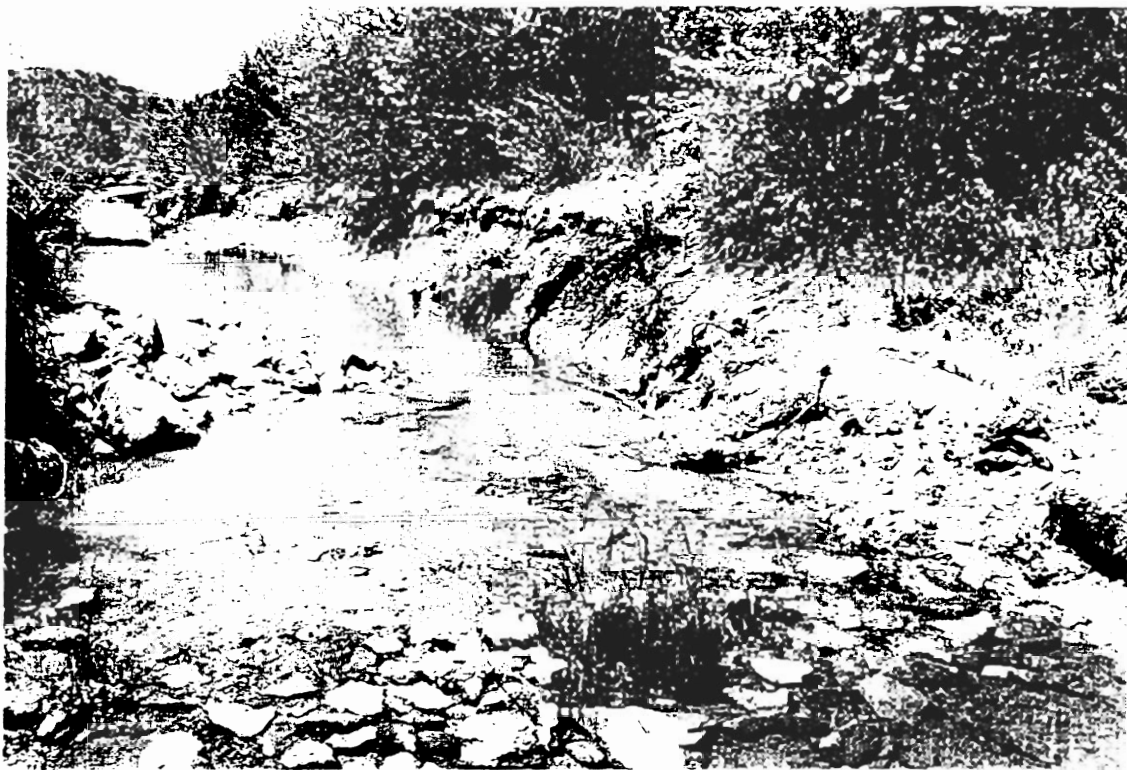
Same view, May 25, 2000. Note more pronounced meander right of riffle. Battle 4. Riffles have shifted right, south bank continues to collapse and flood plain is well developed and expanding.



Phase 1, Baffle 4 - A rock only Baffle, June 1998



Same location as in photo 1 with pickers. 30" of soil has since been added to the face of the embankment.



Phase 1. Riffle 4 Foreground. Baffle 5 midground, left. Both structures rock only. May 21, 1998.



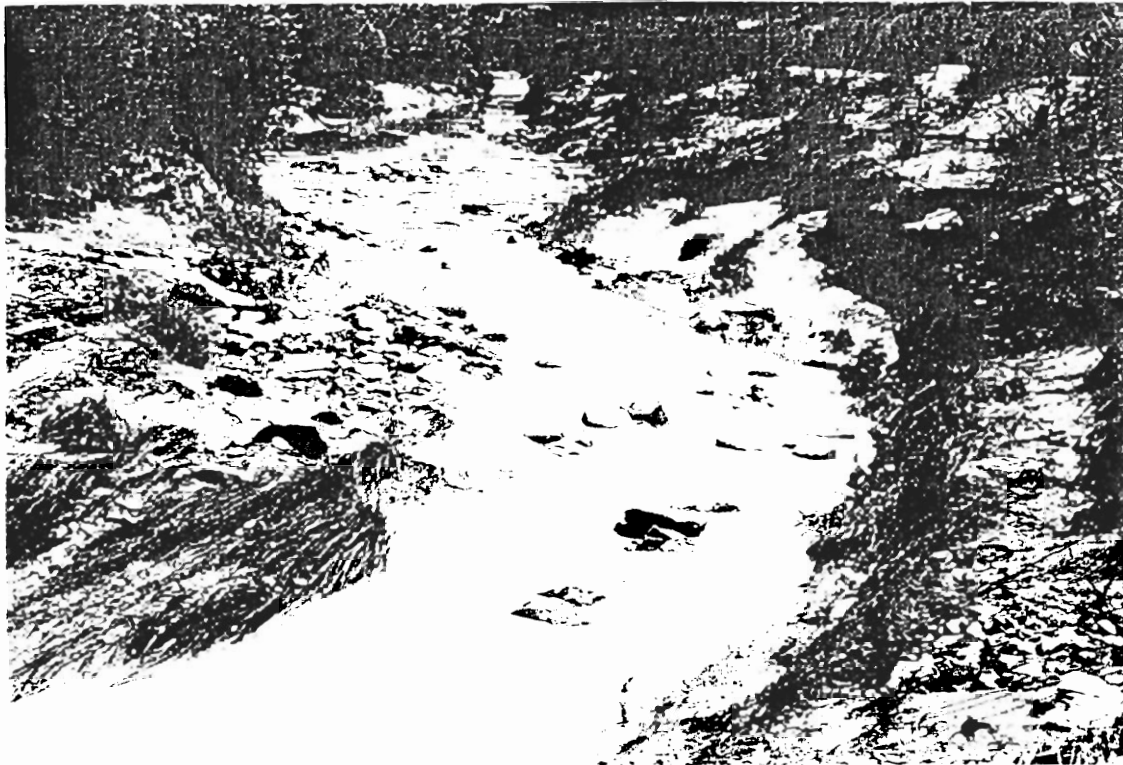
Same site from opposite bank. pickets added to Baffle 5. May 25, 2000



Permanent Photo Point 4 - View east, May 28, 1998



Permanent Photo Point 4 - View east, July 29, 1998 - channel at bankfull stage, 10 cfs, receding from maximum stage of 800 cfs



Permanent Photo Point 4 after July 29, 1998 flood. Baffle 8 (left foreground), Weir 2 (midground). Scattered rocks are from damaged structures.



Spring Creek, May 1999. Photo taken from the same point as above.



A Post Vine at site B3V, Phase 2 Reach, view west, November 2, 2000



Small pond at site B3V, Phase 2 Reach, view west, November 2, 2000. Purple 7 is a Wicker Weir in foreground.



Phase 2, Baffle 5 site. Pretreatment, June 19, 1998



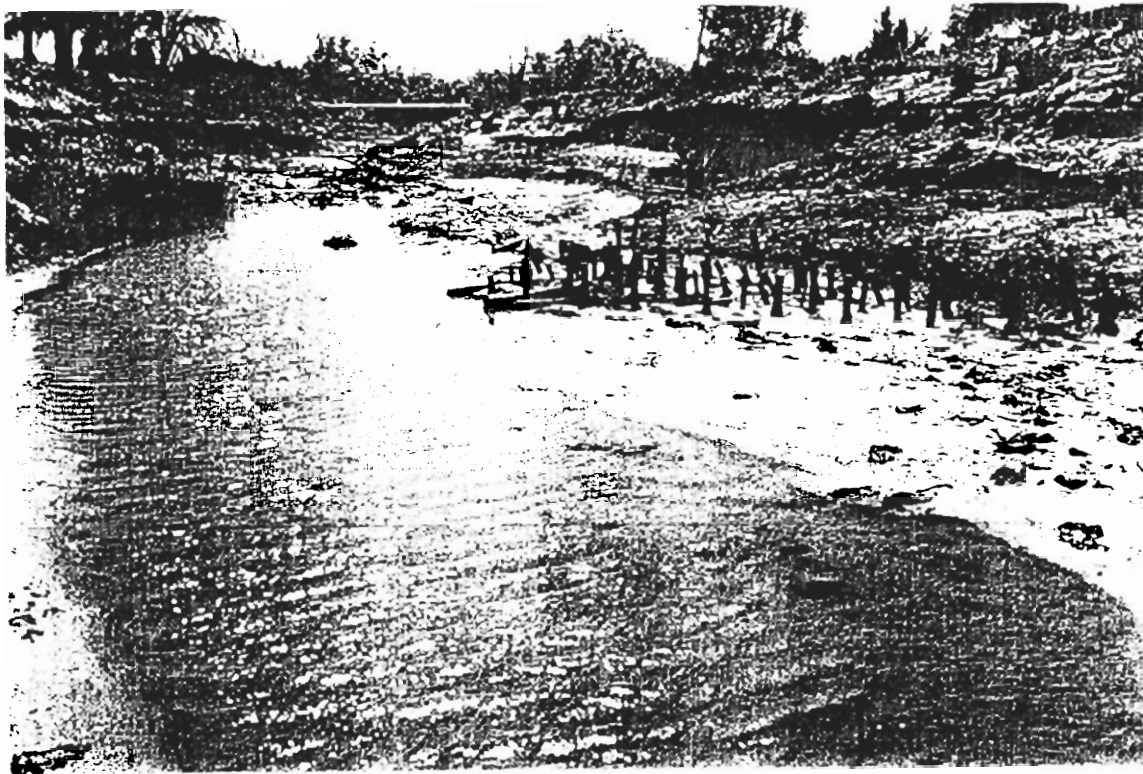
Same view. Phase 2, Baffle 5. As built July 17, 1998. Baffle 7 in mid frame.



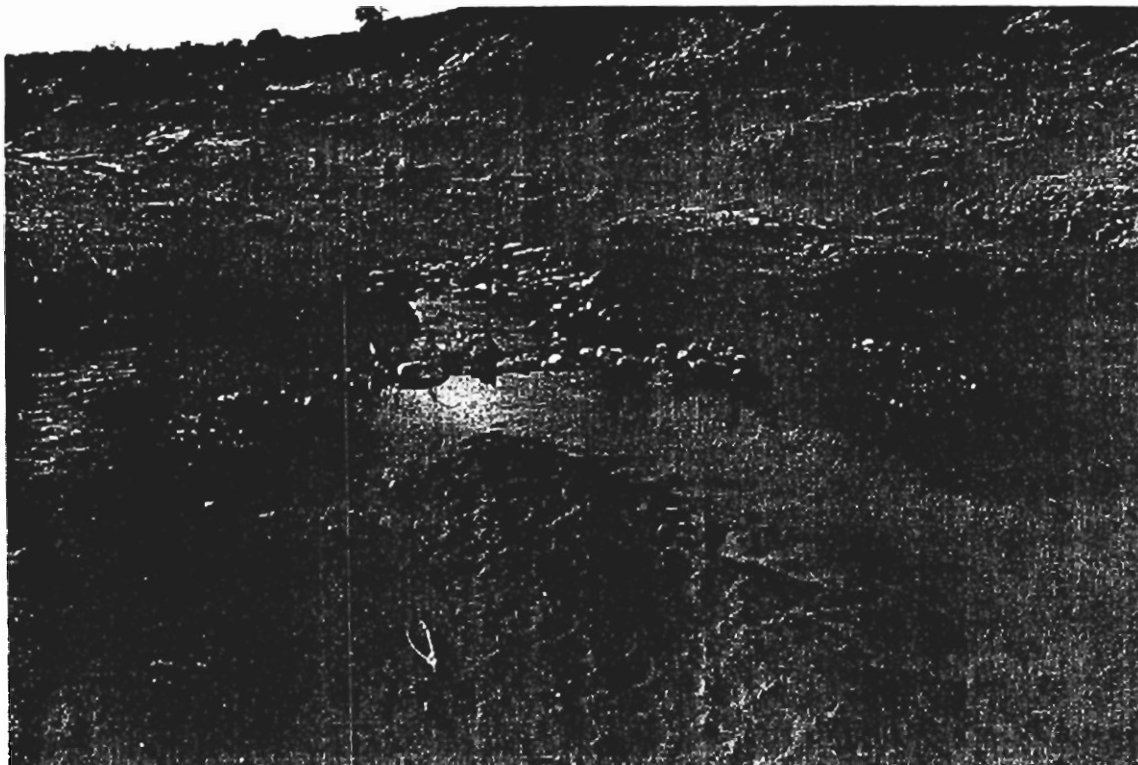
Same view. Bankful discharge July 29, 1998.



Same view. Following spring runoff 1999. June 23, 1999.



Phase 2 - Baffle 5 site. Rock baffle replaced by a picket only Baffle following August 28, 1999 flood.



Phase 2 - site NR4 - A Wicker Weir with cobble added - Structure installed to control flow during incising Kogon G channel generated by July 28, 1999 flood (photo taken Aug 2, 2000)



Students from University of New Mexico planting willows at Phase 2, Riffle 10 site.
March 24, 2001.



THE NAVAJO NATION

Navajo Nation Environmental Protection Agency
P.O. Box 339 Window Rock, Arizona 86515

(520) 871-7690

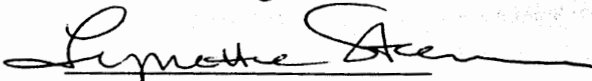
KELSEY A. BEGAYE
PRESIDENT

TAYLOR MCKENZIE, MD
VICE PRESIDENT

MEMORANDUM

DATE: May 10, 2001

TO: Nancy Stone, Superintendent
Hubbell Trading Post

FROM: 
Lynette Stevens, Hydrologist II
Water Quality/ NPDES Program
NAVAJO NATION ENVIRONMENTAL PROTECTION AGENCY

RE: Final Water Quantity Report

Attached is my revised report with the comments we discussed. I decided to merge in earlier deliverables rather than attach them. Additionally:

1. The National Weather Service Ganado Station is at the Arizona Department of Transportation yard just down the highway from Hubbell. You can dial in to the station at 520-755-5910 (to get real-time data), then press #. If you dial in by modem (to get historic data), don't press #.
2. The crest stage gage rating curve has no "implications for the project." The rating curve is used to estimate flow by reading across from the measured stage (added to text). I hand wrote in a figure number on the CSG rating curve in appendix A and the figure in appendix C because I'm having trouble with the electronic files.

I hope I've given you all you need. I'll be out of the office from May 12-May 29. Take care!

APPENDIX III – No Title

DEMONSTRATION ENHANCEMENT OF PUEBLO COLORADO WASH
HUBBELL TRADING POST NATIONAL HISTORIC SITE
GRANT No. 97-029WPF

FINAL SUMMARY OF
WATER QUANTITY MONITORING

PREPARED BY
THE NAVAJO NATION ENVIRONMENTAL PROTECTION AGENCY
WATER QUALITY PROGRAM
MAY 10, 2001

NOTES:

All or a portion of the work for which this deliverable has been prepared has been funded by the Arizona Water Protection Fund Commission. The views or findings represented in this deliverable are the Grantees and do not necessarily represent those of the Commission nor the Arizona Department of Water Resources.

DESCRIPTION OF MONITORING ACTIVITIES

The Navajo Nation Water Management Branch (NNWMB) installed a crest stage gage, precipitation can, and two shallow monitoring wells in fall of 1998. The Navajo Nation EPA Water Quality Program (NNEPA WQ), NNWMB, and Park Service took periodic measurements at these monitoring stations from installation to date.

NNWMB, with the assistance of the U.S. Geological Service, installed a crest stage gage and 0.0 - 6.6 ft staff plate on the left bank of the Pueblo Colorado Wash on 9/2/98 (Figure 1). The purpose of the crest stage gage is to estimate peak flows following large flow-generating events. The gage is located upstream of the AWPf project area, under the highway bridge. This location was chosen because we had planned to attach the gage to the bridge for support during potential high flows. When we got to the site, we decided instead to attach the gage to the old wooden bridge pier stump as well as welding it to a 2- inch diameter pipe that we drove three feet into the channel bottom. Attaching the gage to the stump enables us to reach the gage cap without a ladder. The pipe was reinforced at the base with cement. Indirect slope-conveyance measurements were taken to develop the rating curve in Appendix A. The rating curve is used to estimate flow by reading across from the measured stage after each event. Markings on the crest stage gage inside stick and outside staff plate are recorded quarterly and/or following large events.

The drainage area above the project area is approximately 268 mi² according to BASINS. One direct discharge measurement was taken at the downstream water quality sampling site on 9/24/99. Personnel measured 6.83 cfs. This measurement was taken the day after a rainstorm and is not considered a baseflow measurement. There is an upstream diversion that diverts water from the wash into Ganado Reservoir. The Navajo Safety of Dams Program periodically releases water back into Pueblo Colorado Wash to control the level of the reservoir. Therefore, many of the recorded crest stage measurements are not event-driven, but reservoir release-driven. Based on the estimated rating curve, peak flows at the crest stage gage (CSG) during the project period were as follows:

<u>Between</u>	<u>Peak Stage (ft)</u>	<u>Estimated Q* (cfs)</u>
9/2/98-11/30/98	3.30	670
11/30/98-4/26/99	2.00	225
4/26/99-7/19/99	1.95	220
7/19/99-9/2/99	8.30	~9000**
9/2/99-9/29/99	2.50	327
9/29/99-2/25/00	1.16	80
2/25/00-5/1/00	none recorded	
5/1/00-6/29/00	none recorded	
6/29/00-9/6/00	3.31	675
9/6/00-3/22/01	none recorded	

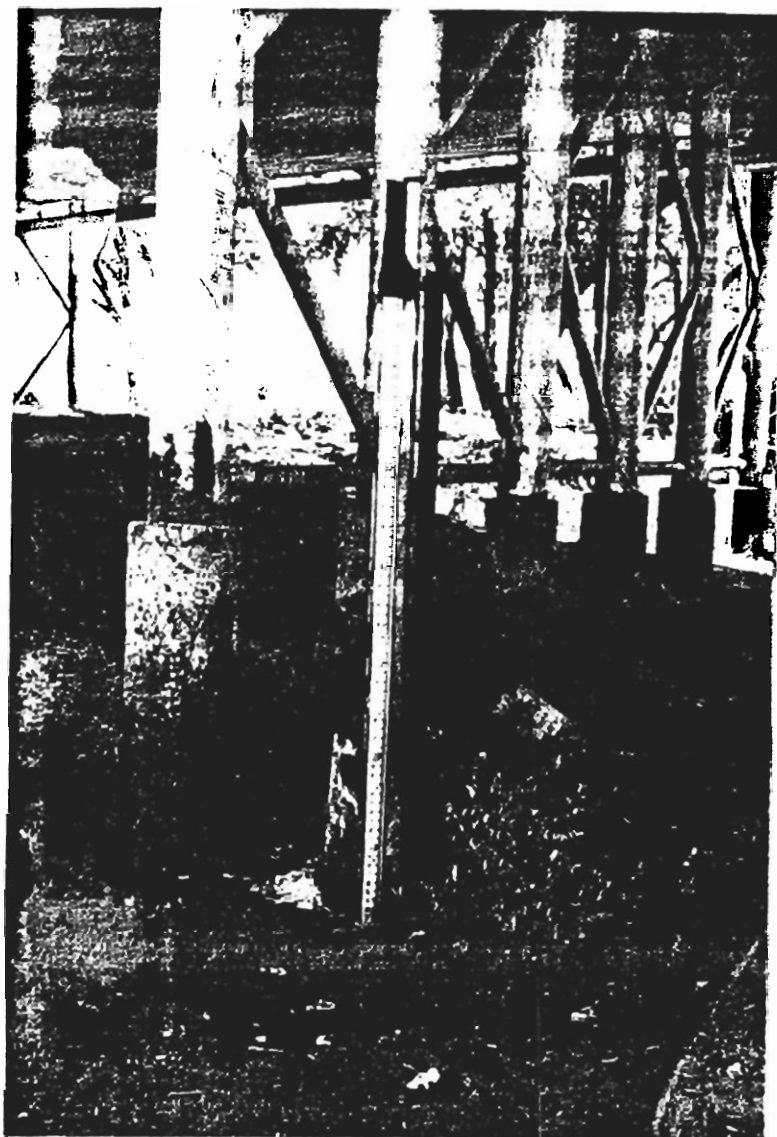


Figure 1. Crest stage gage on Pueblo Colorado Wash under the highway bridge (on left bank). Established 9/2/98 by the Navajo Nation Water Management Branch with technical assistance from the USGS.

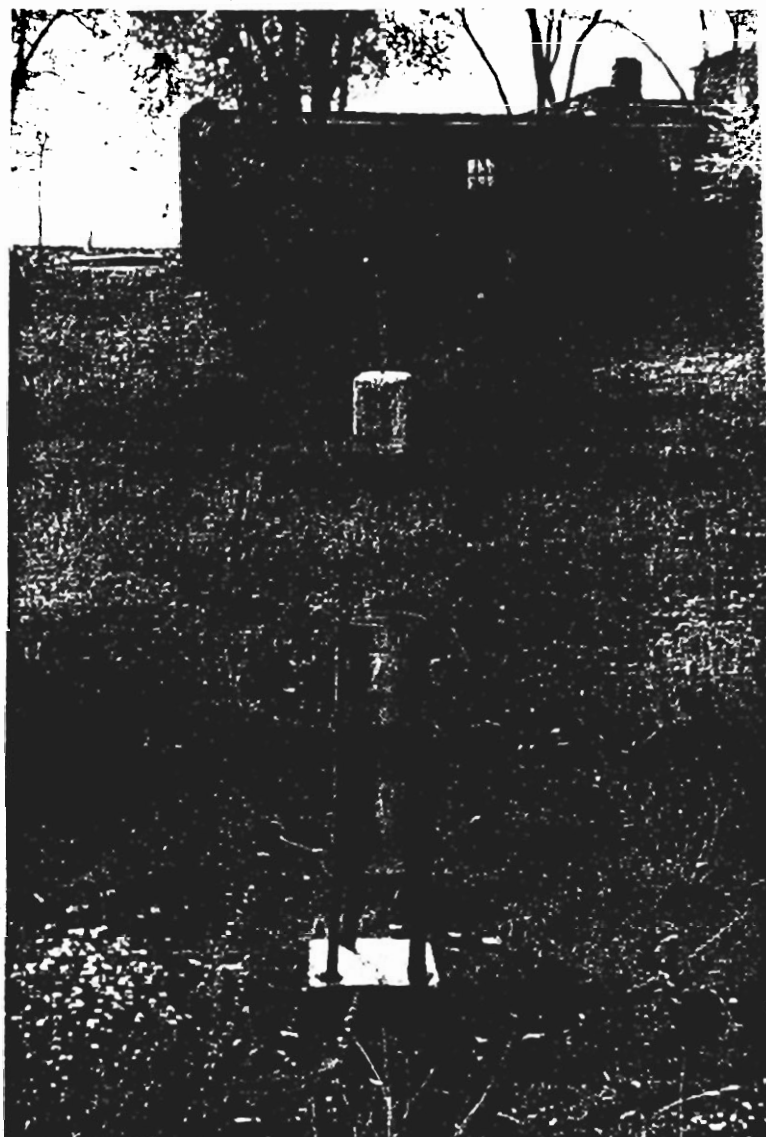


Figure 2. Precipitation can behind Hubbell Trading Post. Established and charged 10/20/98 by the Navajo Nation Water Management Branch.

* this rating curve was based on indirect measurements and has not been verified with an adequate number of direct measurements.

**On Saturday, 8/28/99, at approximately 10:30 pm, the stage at the upstream Kinlichee continuous stream gage (approximately 136-mi² watershed area) almost overtopped the bridge. The stage at this gage crested at 9.0 feet. Since there is a waterfall control at this gage, WMB surveyed the high water marks and used a USGS-recommended free-fall indirect method to estimate peak flow at this gage. The downstream CSG at Hubbell was overtopped during this event. WMB and NNEPA surveyed high water marks and cross-section from this event at the CSG cross-section immediately upstream of the bridge in order to determine cross-sectional area and estimate peak flow. Cross-sectional area during this event was estimated to be 716.5 ft. Differences in main channel vs. overbank roughness coefficients were incorporated into the peak flow analysis. Using a combination of Manning's formula, WMB's upstream analysis, and the survey data used to generate the preliminary CSG rating curve, peak flow was estimated to be 9000 cfs $\pm$ 500 cfs. The re-occurrence interval of this event cannot be determined due to lack of data at the Kinlichee gaging station. It may have been a 100-year event.

NNWMB and Hubbell Trading Post personnel identified a location and installed a precipitation monitoring can on 10/20/98 (Figure 2). The rain can was installed to record both 1) event-based measurements, and 2) monthly measurements. The precipitation rain can network on the Navajo Nation was installed in support of the Standard Precipitation Index (SPI). This drought index was chosen by Navajo Nation Water Management Branch to best represent drought conditions on the reservation. Calculation of the index requires monthly precipitation data, which is gathered from this network of rain cans all over the reservation. The can is located behind the park headquarters, in an open area near the old water pump. The rain can was originally charged to a depth of 2.90 inches with heat transfer fluid and mineral oil at an approximate 6:1 ratio to keep the rain water from freezing and damaging the can. Hubbell Trading Post personnel were provided a dipstick, Precipitation Storage Gage Worksheet, and instructions on how to take and record measurements. NNWMB personnel also took periodic reading of the rain can. The precipitation record based on an eight-inch storage can at Hubbell Trading Post is in Appendix B. In addition, there is a National Weather Service weather station at the Arizona Department of Transportation (ADOT) yard about one mile west of Hubbell Trading Post.

The Navajo Nation had the lowest snowpack in twelve years during Water Year 1999. The Navajo Nation experienced several snow and rain events in late March and April 1999. Possibly a 100-yr-precipitation event occurred 8/28/99 in the Pueblo Colorado Wash/ Kinlichee watershed. Approximately 11.6 inches of precipitation was recorded at the Hubbell precipitation can between 5/5/99 and 10/08/99. Snowpack on the Navajo Nation was approximately 80% of normal during Water Year 2000. Snowpack on the Navajo Nation was approximately 110% of normal during Water Year 2001.

NNWMB installed two shallow monitoring wells on 10/12/98. Both wells were hand-augured with a 3 inch outside diameter augur. Well #W2 (Figure 3) is in Phase 2, located on the left bank approximately 75 ft downstream from the right bank leaning cottonwood, 6 ft toward the channel from orange monitoring rebar at B2. This well was set at 9.5 feet total depth, using 1.5 inch slotted PVC screen (4.5 to 9.5 ft) with 1.5 inch blank PVC casing (-1.5 to 4.5 ft). The annulus was filled with 3/8-inch pea gravel (1 to 9.5 ft) with a bentonite surface seal. Water level



Figure 3. Shallow monitoring well #W2 (looking towards channel). Established 10/12/98 by the Navajo Nation Water Management Branch.



Figure 4. Shallow monitoring well #W1 (looking towards channel). Established 10/12/98 by the Navajo Nation Water Management Branch.

at time of installation was at 6.50 ft below ground surface. The water level on 10/20/98 measured with a chalked steel tape after the well was allow to settle was 5.92 ft below ground surface. Well #W1 (Figure 4) is in Phase 1, located 25 ft upstream of B7 and 23 ft from the left bank. This well was set at 11.75 feet total depth (the limit of our auger), using 1.5 inch slotted PVC screen (6.75 to 11.75 ft) with 1.5 inch blank PVC casing (-1.5 to 6.75 ft). The annulus was filled with 3/8-inch pea gravel (5.75 to 11.75 ft) with a bentonite surface seal from top of gravel pack to seal. There was no water in the well at the time of construction. This site had high amounts of clay. The project team believes that with time, the structures in the channel will result in a higher water table, and that this well will then be useful for monitoring ground water levels. The well logs for these two wells, along with copies of water level logs, are in Appendix C. Figure C-1 in Appendix C displays water levels in the wells by Water Year to account for seasonal fluctuations.

Well #W2 in Phase 2 of the project area had water in the well at the time of construction. Between measurement 2/9/99 and 4/26/99, several cottonwood poles were planted in the Phase 2 project area near the well. The project team believes the water demand from these plantings resulted in a 0.05 ft drop in ground water level at this well between these two measurements. Well #W1 in Phase 1 of the project area was dry at the time of installation. This site had high amounts of clay. As predicted, there has been water in the well from the 2/9/99 measurement on. The project team believes the structures in the channel may be contributing to the rise in the water table at this well. Although it appears that the mean water level in both wells may be rising over time, many years of additional data will need to be collected and interpreted to verify trends due to fluctuations between wet and dry years and between seasons.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE MONITORING ACTIVITIES

Visually, there appears to be more water in the channel for more days during the water year. Whereas before the project, the channel exhibited ephemeral and possibly intermittent characteristics, the channel now appears perennial throughout the project area. The system is regulated by the upstream diversion into Ganado Wash, so the true nature of the stream is difficult to determine. Before the project, there were no riparian grasses on the channel banks. The banks now support sedges and rushes in various locations along the channel. These plants help stabilize the banks and reduce channel erosion.

There appears to be a trend towards rising water levels in both shallow monitoring wells. The trend is more noticeable in the upstream well (#W1) based on the number of observations the well was dry (>11.75 depth to groundwater) in water year 1999 compared to later years. Even so, many additional years of more frequent readings are necessary to accurately quantify changes in groundwater levels in the project area.

Regarding monitoring, we recommend the following:

- 1) Installation of a continuously recording stream gage coupled with the existing crest stage gage – A continuously recording station is necessary to correlate the effects of

various flow volumes with impacts to various in-stream structures in the project area.

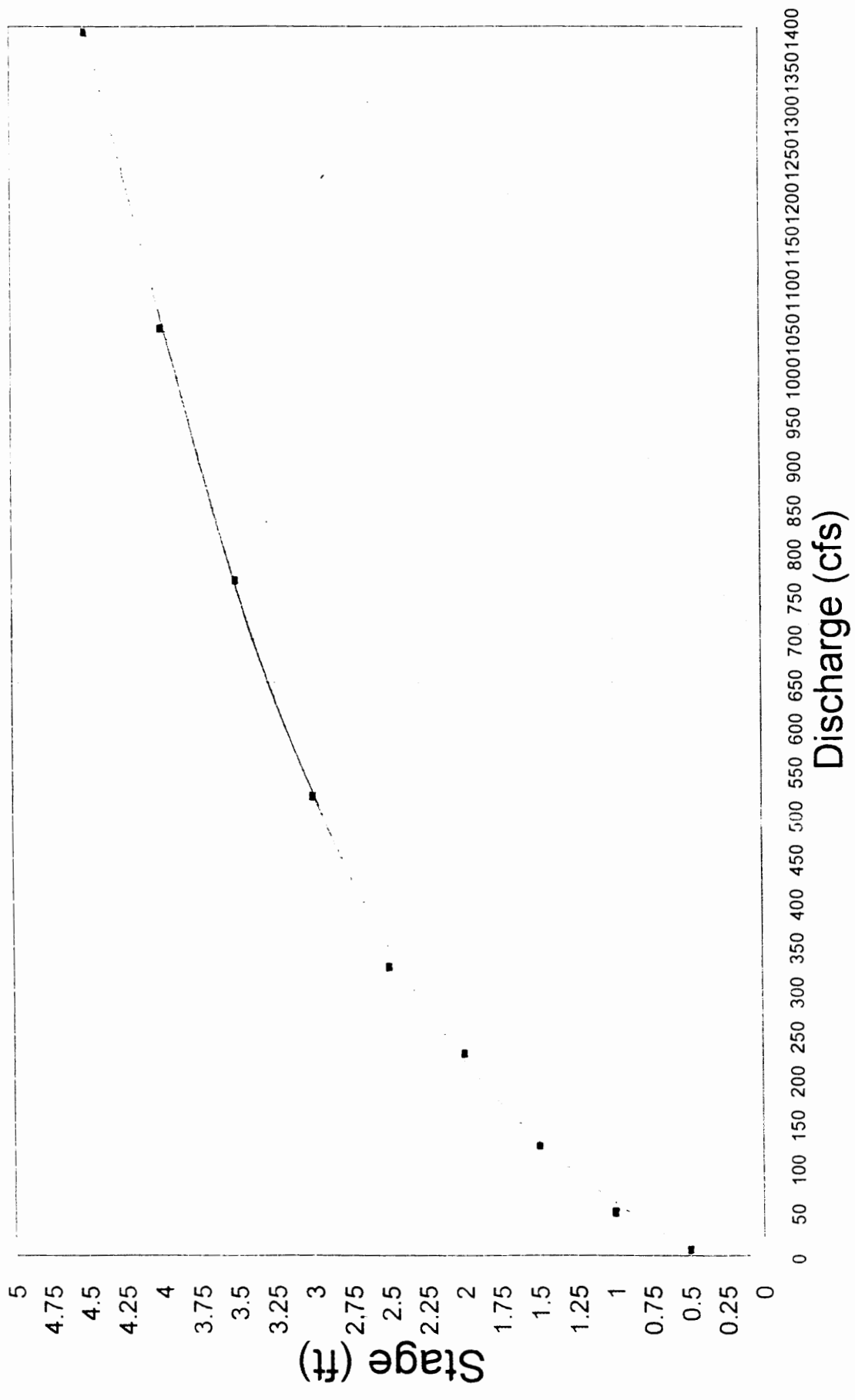
- 2) Installation of a full weather station (or use of National Weather Service weather station at ADOT yard) – A continuously recording weather station would provide additional detail on the exact amount of precipitation received during each storm event. Also, precipitation stations in the upper watershed should be considered.
- 3) Expansion of the shallow monitoring well network coupled with a higher frequency of data collection – Additional data on ground water levels throughout all seasons would provide assist in quantifying changes to groundwater levels in the project area.

APPENDIX A:

STREAMFLOW DATA

Figure A-1. Pueblo Colo Wash nr. Hubbell TP at CSG

Based on slope-conveyance, 9/2/98



* BASED on HWM from
8/23/99 event

(shaded cells are filled by formulas)				Date:		Watershed area	
Stream Name		Pueblo Colorado Wash at CSG		05/01/2000		268 mi ²	
Watershed name		Pueblo Colorado/ Kinlichee		Site Elev.		ft	
Personnel		LS/DG/BJB		USGS Quad			
Longitude		Latitude					
Flow		Perennial / Intermittent / Ephemeral					

Cross-section Data (left to right looking downstream)				Channel cross-section			
STA	ROD HT	Elev	BK1	Depth (ft)	Station (ft)	Left Bank	Right Bank
1	20	27	14.8				
2	120	7.3	10.2				
3	15.4	8.9	8.6				
4	200	10.7	6.8				
5	250	12.0	5.5				
6	300	12.5	5.0				
7	350	12.6	5.0				
8	400	12.7	4.8				
9	450	12.8	4.7				
10	500	13.1	4.4				
11	550	13.5	4.0				
12	600	13.2	4.3				
13	650	13.1	4.5				
14	700	13.7	3.8				
15	750	13.9	3.7				
16	800	14.8	2.7				
17	850	15.9	1.7				
18	900	17.1	0.4				
19	950	17.1	0.4				
20	1000	17.3	0.2				
21	1050	17.5	0.0				
22	1100	17.1	0.5				
23	1150	15.3	2.3				
24	1200	14.6	2.9				
25	1240	13.6	4.0				
26	1270	14.9	2.6				
27	1320	13.0	4.5				
28	1400	11.9	5.6				
29	1450	12.0	5.5				
30	1500	12.5	5.0				
31	1550	12.2	5.4				
32	1600	12.3	5.2				
33	1650	12.5	5.0				
34	1700	12.4	5.1				
35	1750	12.0	5.5				
36	1800	10.6	6.9				
37	1830	9.6	7.9				
38	1900	6.9	10.6				
39	1950	5.5	12.0				
40	2000	3.9	13.7				
TOTAL AREA			716.52	sq ft			

BANKFULL DATA			
Watershed area	288.00	mi ²	
X-section area	716.52	ft ²	
X-SEC Bankfull Width	188.0	ft	
Mean depth	3.8	ft	
Max. Depth	8.3	ft	
Floodprone width		ft - m	
W/D ratio	49.3		
Ent. Ratio	0.004		
Slope	0.004		
D50		mm	
Sinuosity (est)			
Channel Type			

DATA ENTRY			
Thalweg elevation change	ft - m	D15	
Water surface elevation change	ft - m	D50	
Channel length	ft - m	D85	
Sinuosity (est)	ft - m		
Rod Reading @ Bankfull Stage	9.3	ft - m	
Rod Reading @ Water Surface	17.1	ft - m	
Floodprone Width	188	ft - m	
Bankfull width	168	ft - m	
HWM width	168	ft - m	
X-SEC			
Channel Type			
HWM Bankfull Elev.	8.3		
Floodprone elev.	16.8		
Water Surface Elev.	0.4		
Slope	0.004		
X-section area	716.52	ft ² - m ²	
W/D ratio	49.3		
Ent. Ratio	0.004		

Crest Stage Gage Measurement Form

Station:

Robert G. Allen (Garden Walk)

Date	HWM outside staff (ft)	HWM inside stick (ft)	Observer	Comments
9/2/98			LS, FE	CSG installed
11/20/98	3.30	3.50	FE	highest mark; dis. debris dam may have lead to rise
1/30/99	1.42	1.74	FE	second stage mark
4/26/99	2.00	1.95	LS	first mark; hidden more work
7/20/99	1.42	—	LS	second mark; no cork on inside stick
7/19/99	—	1.35 and 1.55	LS	*NOTE light debris in water US Glauco detail at 3.0 ft Earring covering bottom of inside stick & in cork holder of HWM inside & most floating debris in pool removed & 100 ft cleaned outside staff plat
9/2/99	over top	over top	TM	Peak flow on 8/28/99 over top. Highest mark in station gauge 015 & 030 ratings. T flow est 1000 cfs (± 200 cfs)
9/29/99	2.50	2.50	TM/ER	water stage & time read as was 0.65 ft
11/5/99	—	—	LS	stage & time of reading was 0.25 ft & 0.50 hr
02/05/00	1.20	1.16	LS/TM	water level = 0.57
05/01/00	0.45	—	LS/DG	too much in the way of stage & time of reading was 0.40 ft & 0.50 hr
06/29/00	0.48	—	LS/TM	channel completely dry
09/05/00	3.31	3.31	LS/TM	debris on stage; water level 3.31
09/20/01	0.50	water	LS	CSG installed from RR station in 1900s recent pool only 0.50

APPENDIX B:

PRECIPITATION RECORD



NAVAJO NATION WATER MANAGEMENT BRANCH

WATER YEAR

STATION : HUBBLE TRADING POST

2001

SICK

[illegible]

PRECIPITATION RECORD FOR 8" STORAGE CAN

STATION : HUBBLE T.P.

2000

[illegible]

- 00000007 / INM DES - # 4

WATER YEAR

1999

[illegible]

APPENDIX C:

SHALLOW MONITORING WELL DATA

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

HAND AUGURED WITH
3.0-INCH OD AUGER BY
LYNETTE STEVENS AND
MIKE JOHNSON

WELL LOG CONTINUATION SHEET

LOCATED APPROXIMATELY 75 FT
DOWNSTREAM FROM LEANING,
COTTONWOOD AT PHOTO LOCATION

Improvement Number

Improvement Name

Well Name

HUBBELL - WELL #2 (W-12)

Date Drilled

10/12/88
BEGIN: 1130
END: 1300

DEPTH (Feet)		CUTTINGS SAMPLE NUMBER	DESCRIPTION OF MATERIALS DRILLED			WATER YIELD (gpm)	REMARKS (Quality of water, ease of drilling, casing, loss of drilling fluid, etc.)
FROM	TO		TYPE OF ROCK	COLOR	OTHER CHARACTERISTICS (Grain size, hardness, etc.)		
0	0.5		SAND	LIGHT BROWN	VF-M, POORLY GRADED, CLEAN SAND	DRY TO MOIST	
0.5	1.0		SAND w/CLAY	LT RED BROWN	AS ABOVE (0-0.5'), WITH ~10% CLAY	MOIST	
1.0	2.0		SAND w/CLAY	REDDISH BROWN	AS ABOVE (0.5-1.0')	MOIST	
2.0	2.5		CLAYEY SAND	REDDISH BROWN		MOIST	
2.5	3.0		CLAYEY SAND	REDDISH BROWN		MOIST	
3.0	3.5		SAND w/CLAY	REDDISH LT BROWN		WET	
3.5	4.0		CLAY	DR RED BROWN LT CLAYEY	INORGANIC CLAY WITH SAND/GRAVEL. MAY BE WEATHERED CHALK?	MOIST	DIFFICULT TO AUGER
4.0	4.5		SANDY CLAY	DR RED BROWN	AS ABOVE (3.5-4.0) WITH MORE SAND (F-C WELL GRADED)	MOIST	
4.5	5.0		CLAY	DR RED BROWN		MOIST	
5.0	5.5		CLAY	DARKER RED BROWN		MOIST	
5.5	6.0		SANDY CLAY	"		MOIST	
6.0	6.5		SANDY CLAY	"		WET	WATER AT ABOUT 6.5 FEET
6.5	7.0		CLAYEY SAND	RED BROWN	F-C, WELL GRADED SAND w/SILT, CLAY	WET	
7.0	8.0		CLAYEY SAND	DR RED BROWN	AS ABOVE (6.5-7.0') WITH MORE CLAY	WET	
8.0	9.5		SANDY CLAY	REDDISH BROWN		WET	
TD=9.5 FT							WELL SET AT 9.5 FEET TOTAL DEPTH, 1.5-INCH SLOTTED PVC CASING (4.5-9.5 FT) WITH 1.5-INCH PVC CASING 2" (-1.5 TO 4.5 FT), ANNULUS FILLED WITH 3/8-INCH GRAVEL (1-4.5 FT) AND BENTONITE PURRING SEAL.

(Continue on reverse)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

HOLE AUGERED BY HAND WITH
30-INCH OD AUGER BY
LYNETTE STEVENS AND
MIKE JOHNSON

LOCATED APPROX. 25' S OF
VLS OF W. 24 N. 10 E. 1/4
1900 LBS

WELL LOG CONTINUATION SHEET

Improvement Number
Well Name
HUBBELL WELL #1 (W-1)
Date Drilled
10/12/98
Begin: 1400
End: 1630

DEPTH (Feet)		CUTTINGS SAMPLE NUMBER	DESCRIPTION OF MATERIALS DRILLED			WATER YIELD (gpm)	REMARKS (Quality of water, ease of drilling, casing, loss of drilling fluid, etc.)
FROM	TO		TYPE OF ROCK	COLOR	OTHER CHARACTERISTICS (Grain size, hardness, etc.)		
0	0.5		SAND	Light Brown	VF-M, Poorly Graded Sand with silt	DRY	AUGERING EASY
0.5	1.0		SANDY CLAY	Reddish Brown Dark	INORGANIC CLAY WITH VF-M SAND, WELL-GRADED, SOME F-C GRAVEL	"	AUGERING VERY HARD
1.0	1.5		SANDY CLAY	" "	AS ABOVE - (0.5-1.0 FT)	"	" " "
1.5	2.0		SANDY CLAY	" "	AS ABOVE - (0.5-1.0 FT)	"	" " "
2.0	2.5		"	" "	"	"	" " "
2.5	3.0		"	" "	"	"	" " "
3.0	3.5		"	" "	"	"	" " "
3.5	4.0		"	" "	"	"	" " "
4.0	4.5		"	" "	"	"	" " "
4.5	5.0		"	" "	"	"	" " "
5.0	5.5		"	" "	" (but sampled)	"	" " "
5.5	6.0		"	" "	"	"	" " "
6.0	6.5		"	" "	"	"	" " "
6.5	7.0		"	" "	"	"	" " "
7.0	7.5		"	" "	"	"	" " "
7.5	8.0		CLAY	Reddish Brown	"	MOIST	"
8.0	11.0		CLAY	" "	"	MOIST	"
11.0	11.75		CLAY	Dark Gray Dark Red	"	MOIST	"
TD = 11.75'							

WELL SET AT 11.75 FT. 1.5" MCH SWEETED PVC C-PIPE (6.75-11.75)
1.5" MCH BURNED PVC (11.5 FT-11.75) ANNULAR SPACE (6.75-11.75)
BEWENTONITE SEAL FROM TOP Form 7230-2a (July 1988)
OF G. A. C. F. P. 10 SURFACE

(Continue on reverse)

U.S. DEPT. OF INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

GROUND WATER SITE INVENTORY WATER-LEVEL DATA

Site Ident. No.	410BB31L	#	32
-----------------	----------	---	----

R = 234	*
T =	A *

*
A
T =

ALY. LSD—MSL

1

[illegible]

acade water levels above LSD with a minus sign (-).

GPO : 1976 OL-214-152

Method of Assessment

239 =	A	C	E	G	H	L	M	R	S	T	V	Z
	airline	calibrated, airline	estimated, pressure, gauge	pressure, gauge	calibrated, pressure gauge	geophysical, logs	manometer, reported	reported, steel, tape	steel, tape	electro, tape	calibrated, electro tape	other electro tape

Site Status

238 =	D	E	F	G	H	Ø	P	R	S	T	V	X	Z
	dry,	flowed	flowing,	nearby,	nearby,	obstruction,	pumping,	recently,	nearby,	nearby,	foreign,	surface-water,	other
	recently		flowing	flowing	recently			pumped	pumping	recently	substances	effect	
				flowing						pumped			

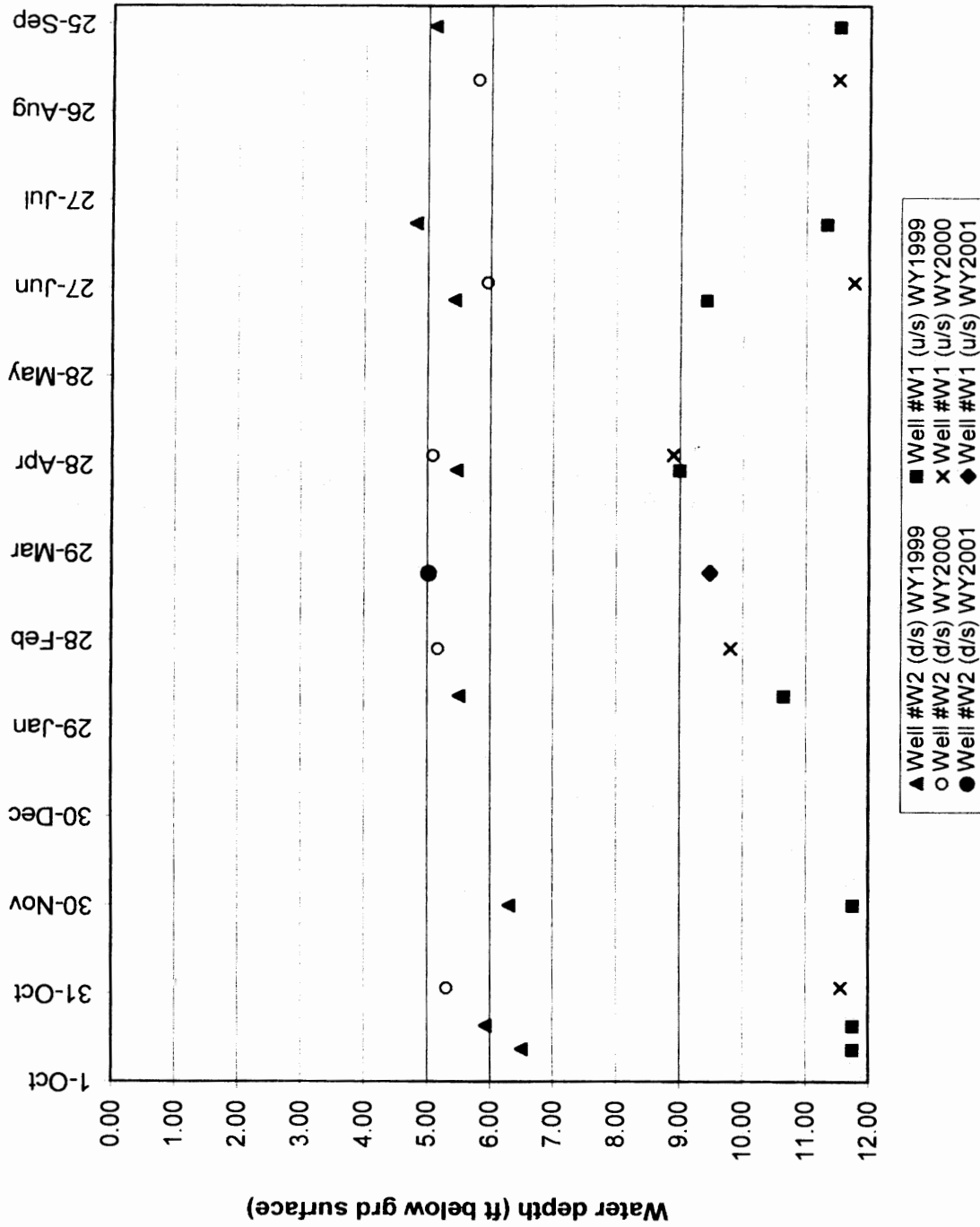
ON 773A

32

U W M F B

Sketches on back

**Figure 4: Pueblo Colorado Wash
shallow monitoring wells**



Chapter 7 - Exotic Species Removal

This component of the project was provided as an in-kind match by the National Park Service (NPS) Exotic Species Removal Team, crew of six, stationed at Lake Mead National Recreation Area. During this first grant period (1998-2000), they came to the park three times (97,98,99), staying 4-5 days each time. All the Russian Olive/Tamarisk (approx. 20 acres) were cleared and treated within the initial project area except for the northeast end which we purposely did not cut so as to buffer a home site adjacent to the park.

Permits were secured from NPS and the Navajo Nation Pesticide program. The crew was housed by the park, and they utilized the park maintenance shop to maintain their tools. In two of the three years, they worked in snow. The crew employed the cut stump/immediate treatment methodology. They maintained records of how much Garlon IV was used. Garlon IV was applied with a back-pack sprayer after the plants were cut close to the ground with chain saws. The Garlon IV is tinted with a red oil so the applicator can see where it has been applied. Evidence of effect is noticeable in drooping, wilted leaves and stems the day after application. Cut branches were collected in piles for burning later in the season.

In 1999, the livestock exclusion area was extended by about 1/4 mile to the west to be contiguous with the park boundary. The extension area (approx. 8 acres) will be cleared and treated in 2001. Funding has been secured from a Public Land Corps grant to address that remaining section.

NPS staff monitored the resprouts fairly casually and retreated new growth several times during the summer and fall. Initially, a 30-40% resprout occurrence was estimated but with each successive year, the occurrence rate has decreased. If left untreated, the resprouts grow very quickly and would reestablish the community. However, this tendency is tempered by soil moisture conditions, and competition with native species.

In 2000, NPS purchased a new tool for Garlon IV application. The EZJECT Lance and capsules held much promise in terms of concentrated application, ease of application and safety for the applicator (the backpack sprayer can leak and the spray blow onto the applicator). The field experience however revealed several problems with the new system. Small resprouts are too thin and weak to allow for capsule injection. The lance mechanism jams fairly easily, and the dosage for capsule effectiveness appears to be higher than the literature claims. The tool would seem to work best when eradicating individual large plants or thinning an area gradually (such as our buffer area).

Resprouts were treated several times in October, 1999 by the NPS work coordinator for this project, using a back-pack sprayer. The small to medium resprouts were sprayed directly with the diluted Garlon 4 mixture. Evidence of effect is noticeable in the drooping, wilted plant the day after application.

Because the riparian area along the Wash has been newly disturbed, other exotics have invaded and emerged such as Russian thistle, Spotted Knapweed, Musk Thistle, cockleburrs and buffalo burrs. These invasions will be tracked for degree of incidence.

Conclusions on Exotic Species Removal:

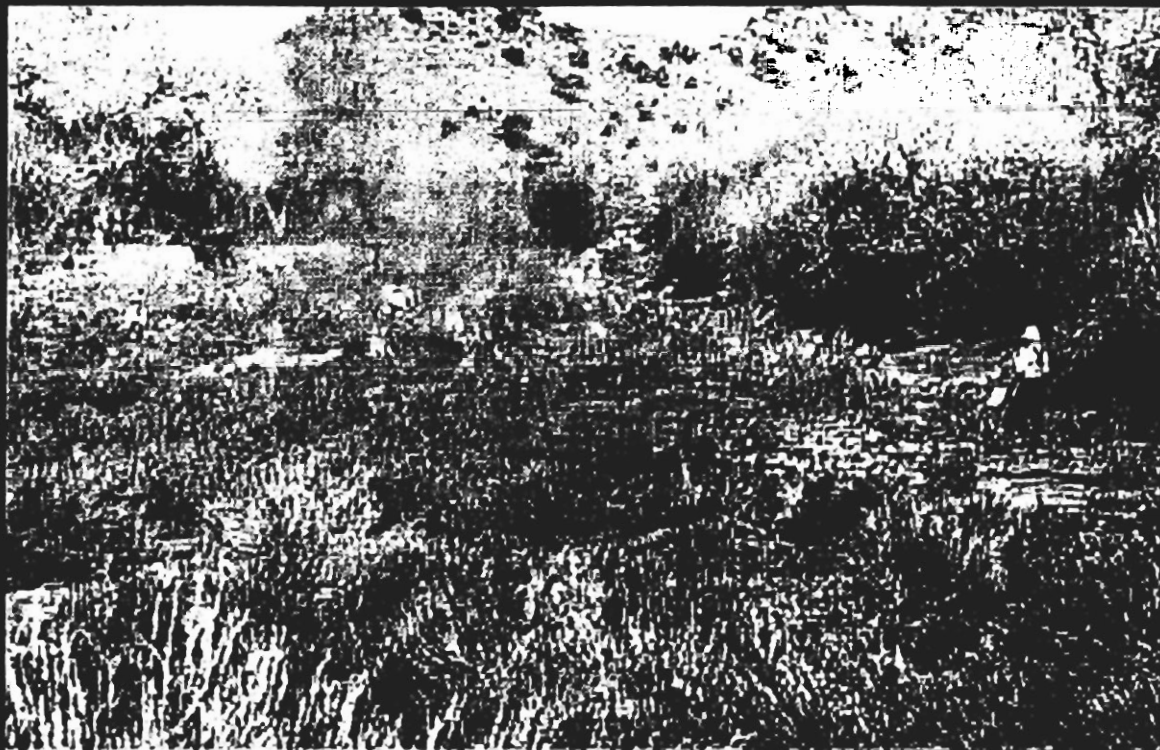
- >Removal and treatment of dense thickets of Russian Olive/Tamarisk was accomplished in less time than was expected (estimate 1/2-3/4 mile in 3 days).

- >Inconclusive as to whether treatment of exotic species with Garlon IV is more effective applied in the spring or the fall.

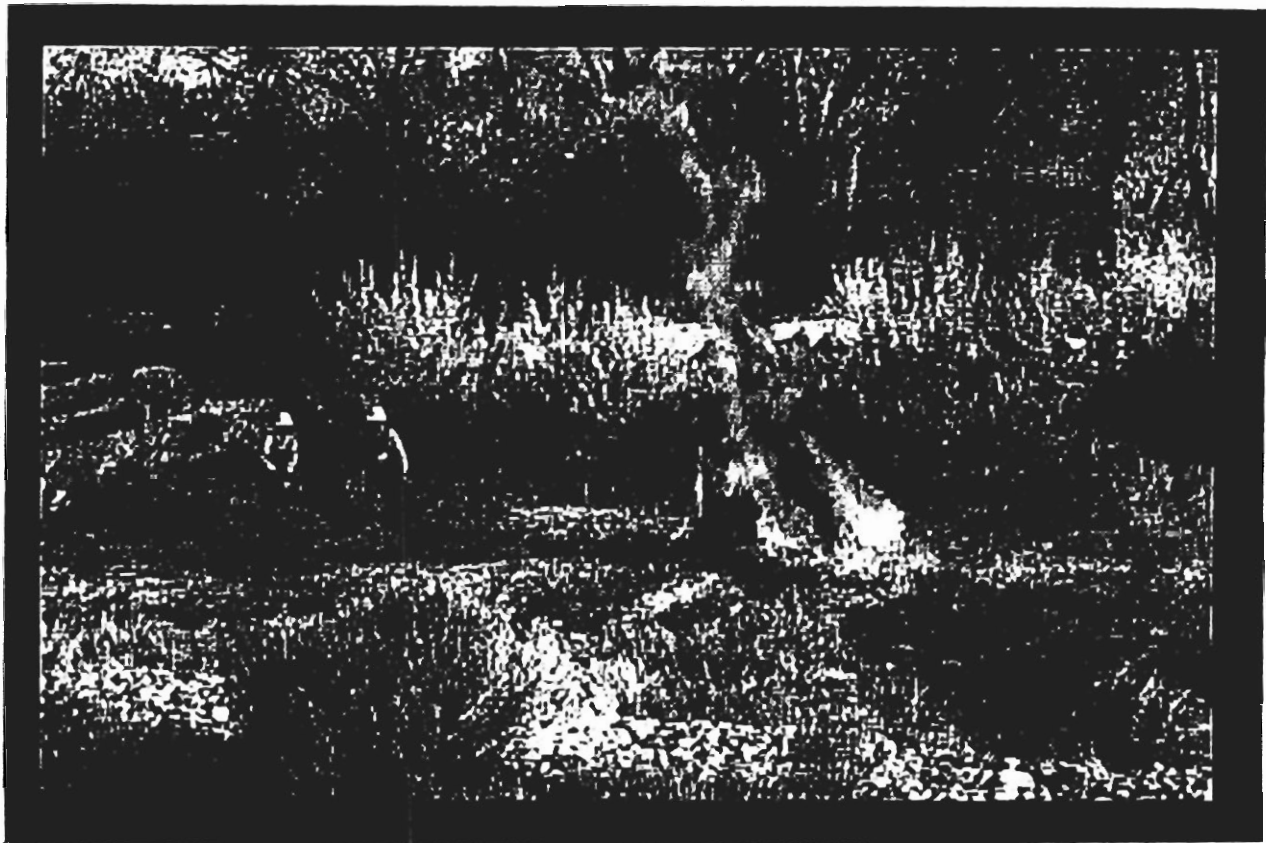
- >New tool, EZject Lance, for application of Garlon IV needs more experimentation to determine its full value in eradication. It may be ideal for the selective elimination of trees on the northeast end of the project where we need to continue to buffer an adjacent homesite.

- >Initial rate of resprout after treatment with Garlon IV is rather high but with continued treatment, the rate falls off and containment becomes easier although it is still necessary to be vigilant to resprouts.

- >Disturbed areas are generally attractive to invasions of other exotic species and Russian Thistle especially, has been observed in the areas where the Russian Olive/Tamarisk was removed.



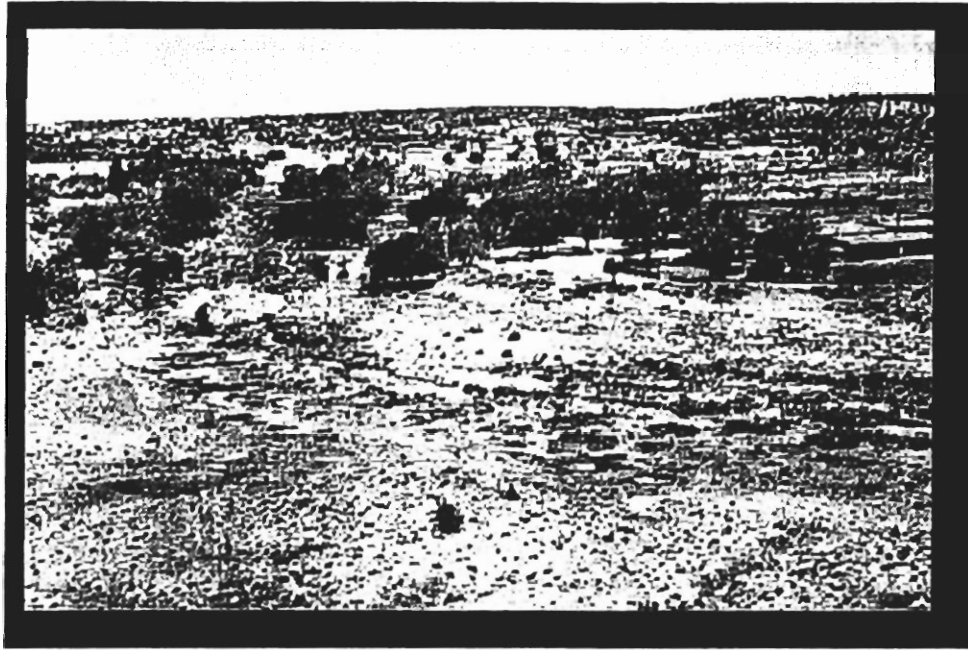
Burning of Russian Olive/Tamarisk slash 1998



Burn Activities



Buen Activities



North side - Phase II
AFTER Burning 1999

Chapter 8 - Riparian Revegetation

The revegetation activities of this project realized a dual role. Revegetation with native plant species in the riparian zone (after exotic species removal) aims at recapturing a native species community as well as restoring the cultural landscape of this historic site at about the time that John Lorenzo Hubbell was at the height of his trading empire. Specific restoration techniques discovered during implementation of the project were used to strengthen and support the intent of the instream structures in meander development. *Scirpus/Juncus* were transplanted from where they are displaced (in the construction of instream structures) to the upstream edge of newly built structures where they anchor and stabilize the structures while increasing resistance to shear stress forces.

The objectives were to:

- a. Stabilize point bars, capture sediments and increase surface roughness, which will tend to divert surface flows toward opposite bank.
- b. Capture and remove bedload and suspended sediments
- c. Create habitat for vertebrate and invertebrate species.
- d. Restore the nearly "more natural" riparian character of the historic site.

To achieve these objectives:

- Cottonwood poles and willow cuttings were planted along the outside of meander bends during the dormant season to stabilize the meander when it reached its optimum bend.
- Rooted willow stock and *Scirpus/Juncus* plugs were planted to stabilize and maintain instream structures.
- Willow, cottonwood and herbaceous materials were removed and transplanted from streambanks opposite baffles to use elsewhere for stabilization and to allow these areas to erode easier.
- Exotic plants, root wads and sprouts were removed and destroyed from the streambanks.

In preparation for any staff or volunteer planting events, cottonwood poles were gathered from several sources at Hubbell Trading Post National Historic Site and one source upstream from the park but along the Pueblo Colorado Wash in order to maintain the same local genetic stock.

The cottonwood sources varied by the age of the tree, and each pole was initially coded to reflect the source for monitoring and analysis purposes. All the poles were put directly into the water of the Pueblo Colorado Wash until they were actually placed in the ground. Directions with proper planting techniques were provided for all participants. Planting zones were predetermined along the Wash to correlate with the objectives above for the channel configuration. Bill Zeedyk, the project consultant, roved around observing the work and answering questions about soil type etc. Monitoring forms were completed shortly after the event by Bill Zeedyk and Nancy Stone. This proved to provide greater continuity and reliability in the observations throughout the revegetation areas. The attached revegetation monitoring forms were developed in consultation with AWPf advice and indicate what was recorded at each site.

Two revegetation monitoring inspections, (3/16/99 and 5/27/99) were conducted on the cottonwood poles and willows planted along the Wash in March 1999 and two monitorings of the revegetation planted in March 2000 took place, once on March 16 and once on April 26. The first monitoring was probably conducted too quickly after planting but the second monitoring yielded a surprisingly good response. Of the two willow species, the Navajo willow, (not the coyote willow) flourished, and it should return in 2001. Most of the cottonwood poles displayed buds or flowers, and several poles that were considered lost in the 1999 monsoon event have become leafy little trees. *Scirpus/Juncus* instream vegetation thrived primarily due to elimination of livestock.

Although the survival rate within the first two months of the 2000 planting was very high, a decline in survival became apparent during the summer heat and relatively light monsoon season. The summer drought of 2000 dramatically reduced the water flow in the Pueblo Colorado Wash. By June, 2000, the only water in the channel emanated from the springs at the east end of the project area. No water was flowing over the waterfall. The cottonwood poles with their promise of buds and development of leaves could not sustain growth. Although they were planted in sandy not clay soil conditions, upon examination of a sample of poles that did not survive, they did not appear to have developed a root system. However, recruitment of tiny cottonwood seedlings from adjacent tree seed sources was much more numerous and visible than in the past. Some of these seedlings appeared to flourish, and they have

been tagged for monitoring during 2001. Three cottonwood poles have survived since the 1999 plantings and have flourished at the west end of the project.

Then several large water events associated with the summer monsoon season inundated many of the plantings for too long a period. The monsoon events in both 1999 (now calculated at 9,000 cfs with a depth of 11-13 feet) and 2000 seriously impacted the cottonwood poles. Most were literally broken off at ground level, swept away by the force of the water or were inundated with water for several weeks. Although a total loss of plantings was assumed, this turned out not to be the case. Rejuvenation of some of the cottonwoods, most of the willows and most of the instream *Scirpus/Juncus* vegetation has occurred, and several bullrush clumps have also been identified in various locations.

The instream channel vegetation on sand bars and floodplain has become a thick mat of grasses, reeds and sedges that lays down during the bankful events and springs back within a few days after the high water subsides.

Rabbit brush has populated the terraces and has all but obscured the scorch marks from the burning of the slash piles of exotic species. The diversity of riparian vegetation has increased significantly since our original vegetation inventory. In 2001, we should be able to conduct another riparian vegetation analysis to monitor the change and verify the diversity increase.

During the summer of each year, as the Student Conservation Association work crew maintained and modified the instream structures, they continued to transplant clumps of the instream vegetation to armor and buffer the structures. The vegetation adapts quickly to the transplant, and most of the structures display a fringe of vegetation that is evident in some of the photographs.

Conclusions on Revegetation

>Monitoring was inconclusive because of devastating effect of flood events masked all other variables. Although monitoring on the forms was only completed twice, approximate survival of the cottonwood poles was observed to be low.

>Natural recruitment of cottonwoods from the seeds and root sprouts from nearby existing trees produced an abundance of tiny seedlings on the banks and terraces, surviving further from the water than what would be expected. Ten to fifteen of these have developed to 4-9 foot plants as of this date primarily due to the livestock exclusion. They have been marked for monitoring. This type of natural regeneration may prove to be more effective than planting of the poles.

>Willow cuttings, both coyote and Navajo, do much better in planting than do cottonwoods.

>Rabbit brush is proliferating on the upper terraces where the Russian Olive/Tamarisk have been removed. Their establishment seems to deter the re-invasion of the exotics.

>The upper terraces have recovered substantially after the burning of the slash piles of exotics.

> *Scirpus/Juncus* plugs are salvaged at strategic points to encourage erosion of the streambank, and they are transplanted upstream along the edges of the structures to stabilize and encourage sediment deposition. The plugs transplant extremely effectively.

>The large event summer monsoons are very disruptive to planted materials which may not have developed a root system strong enough to hold them during inundations.

>Tentatively, the poles taken from young cottonwood trees on Site, planted in sand and gravel with maximum trim appear to have the highest survivability rate for cottonwood poles.

Chapter 9 - Community Education and Involvement

An integral part of this project is the education of the local community, both school age and adults, and the demonstration nature of the project. In 1999 and 2000, a Park Ranger developed semester and year-long curriculum based projects with the Ganado Intermediate School involving multiple classroom visits and field trips to the historic site. The subject matter consists of a variety of topics from the Arizona Education Standards such as measuring, constructing tables, charts and graphs; organizing gathered data into an appropriate format, identifying human and environmental needs; describing the components of an ecosystem and describing how living and non-living components interact within an ecosystem. The outreach program covers subjects related to riparian ecosystems, biological diversity, native and exotic species, waste management, recycling, water quality monitoring, practical Internet applications, topographical map reading, environmental restoration and gathering of scientific data. A central theme of the curricula revolves around the presence of exotic plant species and their impact on riparian ecosystems. Students are afforded many opportunities to experience how exotic plants reduce biodiversity, contribute to erosion, reduce ground/surface water levels and affect water quality. They are also provided with increased hands-on learning opportunities (planting, measuring and identifying) and exposure to career paths (NPS and Navajo Nation agencies) they may not have realized exist.

For three years, summer work was provided for 4-5 Navajo youth through a Public Land Corps grant. The park is allowed to hire youth from the community paid for by Student Conservation Association, and this has meant gainful employment in a region where summer jobs are few and far between. USEPA and NPS funds have supported a work coordinator also from the community. Providing local jobs is a significant feature which attracts local involvement in the project.

Adults are becoming aware of the restoration model this project affords the Navajo Nation. As NPS restores the cultural landscape of this natural environment, resource stewardship of a prominent waterway is being demonstrating. This waterway, for years, played a significant role in attracting human settlement to this valley and provided the basis for the agrarian economy in Ganado. The visibility and accessibility of this project on public land should encourage our Navajo neighbors along other reaches of the Wash to adopt this example of environmental stewardship.

Chapter 10 - Grants, Awards and Publicity

Enhancement of the Pueblo Colorado Wash at Hubbell Trading Post National Historic Site, has attracted the attention of other agencies, garnered awards and publicity and been highlighted in several publications.

>The Pueblo Colorado Wash Demonstration Enhancement project has received three Public Land Corps grants totaling \$60,000 to hire youth from the community of Ganado, Arizona to assist during the summer season in the implementation of the enhancement work. The youth are hired as conservation associates under a National Park Service cooperative agreement with the Student Conservation Association.

>The Pueblo Colorado Wash Demonstration Enhancement project was selected by the Five Star Restoration Challenge Grant Program for a grant of \$13,200 for 1999 to hire a work group coordinator to oversee the Public Land Corps crew in their work efforts during the summer of 1999. This grant is administered by the National Fish and Wildlife Foundation on behalf of the Five Star Partnership which includes the U.S. Environmental Protection Agency, the National Fish and Wildlife Foundation, National Association of Counties, Wildlife Habitat Council and the National Association of Service and Conservation Corps. The first ever Five-Star Restoration Partnership bronze plaque was presented to the summer youth crew during a site visit and project tour by US EPA Assistant Administrator for Water, Region IX EPA Administrator, Felicia Marcus and Navajo Nation EPA representatives.

>Hubbell Trading Post National Historic Site received two years of funding from the National Park Service Water Resources Division to complete a Level I Water Quality Inventory and Monitoring project for the Pueblo Colorado Wash. Funds from the National Park Service were transferred to the U. S. Geological Survey to complete the water sampling and analysis.

>The New Mexico Riparian Council has sponsored three volunteer events in early spring of each year to plant cottonwood and willow cuttings and complete minor maintenance projects along the stretch of the Wash. These plantings serve as the foundation for our revegetation efforts and the summer youth crews plant additional cuttings later in the year.

>A teacher at University of New Mexico, Ellie Trotter, has brought her classroom students to the project for two years to acquaint them with our approach to enhancement/restoration and to involve them in work on the project. They camp out for the weekend and receive a project overview from Bill Zeedyk.

>The Little Colorado River Watershed Multi-Objective Management group visited Hubbell Trading Post National Historic Site on a field trip in 1999 to view restoration/enhancement in process. This group consists of representatives of local cities, counties, tribal agencies, federal agencies and citizen groups interested in a watershed improvement and stewardship of the Little Colorado River. Bill Zeedyk presented the conceptual design and restoration theory and then guided the group on a walk along the Wash to view the implementation.

>Bill Zeedyk and Nancy Stone presented a poster session on the Pueblo Colorado Wash Enhancement project for the Arizona Water Protection Fund Information Transfer Conference in Phoenix March 22, 2000.

>A short article with a photograph on the Pueblo Colorado Wash Enhancement project was submitted and accepted for the National Park Service Natural Resource Year in Review publication.

>Nancy Stone received the Superintendent's Intermountain Regional Award for Natural Resource Management in a Small Park based on our accomplishments in the Pueblo Colorado Wash Enhancement project.

>Two separate school classes from Ganado Intermediate School were involved in school projects and curricula directly related to the Pueblo Colorado Wash. Each class visited the park and was involved in field work twice. A park ranger visited their classroom to prepare them for the field work.

>Photo of Pueblo Colorado Wash project included in AWPf brochure.

>Poster session on "Induced Meandering" delivered by Bill Zeedyk at the USEPS, Region 6, NonPoint Source Watershed Conference, May, 2000 at Angel Fire, New Mexico and in Bernalillo, New Mexico in

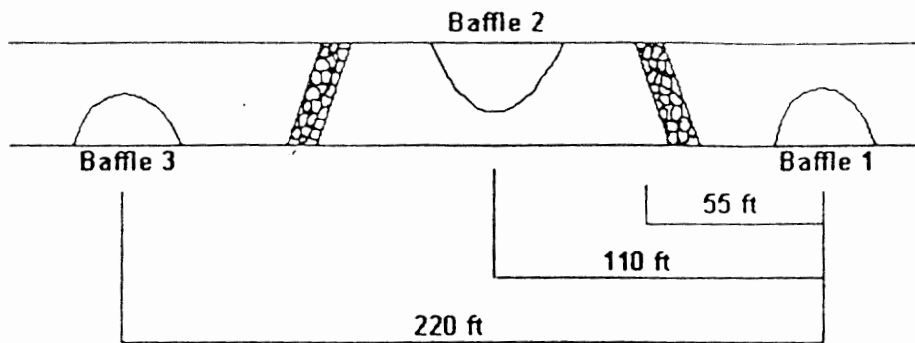
March, 2001 for the "Success Stories in Riparian Restoration" for the New Mexico Riparian Council conference.

>Written adaptation of that poster session appeared in "Clearing the Waters", newsletter of the NonPoint Source Pollution Section, New Mexico Environment Department, August 2000.

>Presentation to Arizona Water Protection Fund Commission for a second three year grant to continue monitoring and improvement of the Pueblo Colorado Wash Enhancement project. Grant awarded November, 2000.

>Submission of Pueblo Colorado Wash project, funding history and accomplishments in support of continuing the Lake Mead Exotic Plant Management Team and forming a new Colorado Plateau Exotic Plant Management Team proposal to the National Park Service, National Resource Challenge funds, November, 2000. Both teams were funded.

Typical Dimensions



Bankfull width (W_{bkf}) = 27 feet

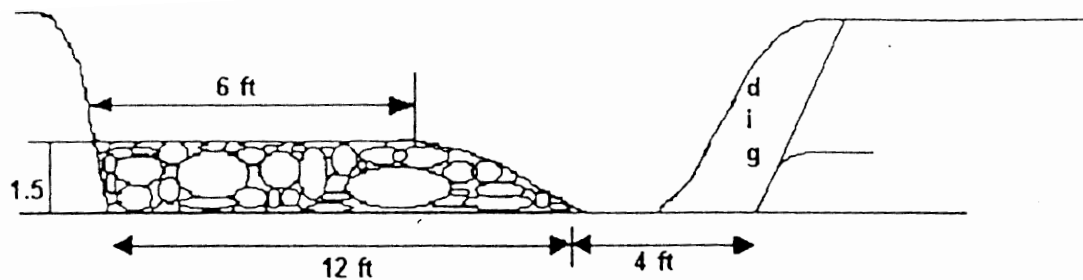
Bankfull depth = 1.5 feet

Full meander length in reference reach is 310 feet; sinuosity 1.4

To establish sinuosity of 1.4 in treated reach which does not meander, multiply 310 times 0.7, to determine distance between apices of one full meander length, equals 220.

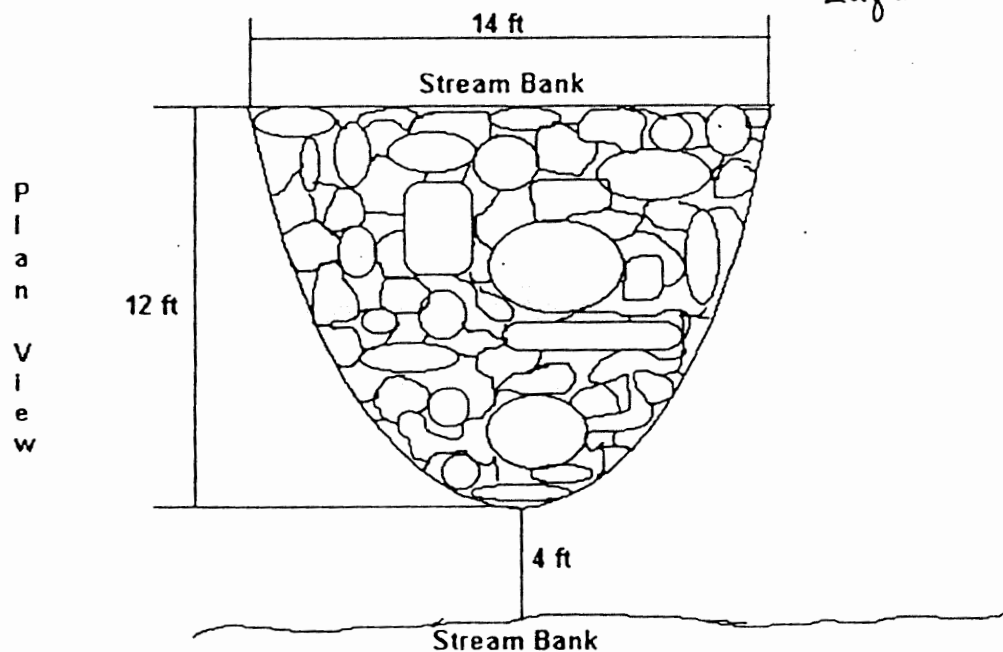
Distance between $\frac{1}{2}$ meander loops is $220/2$ equal 110 feet, distance between baffles. Height of baffles 1.5 feet. Riffles are placed at $110/2$, equals 55.

Channel gap between tip of baffle and edge of channel should be from 4 to 10 feet wide



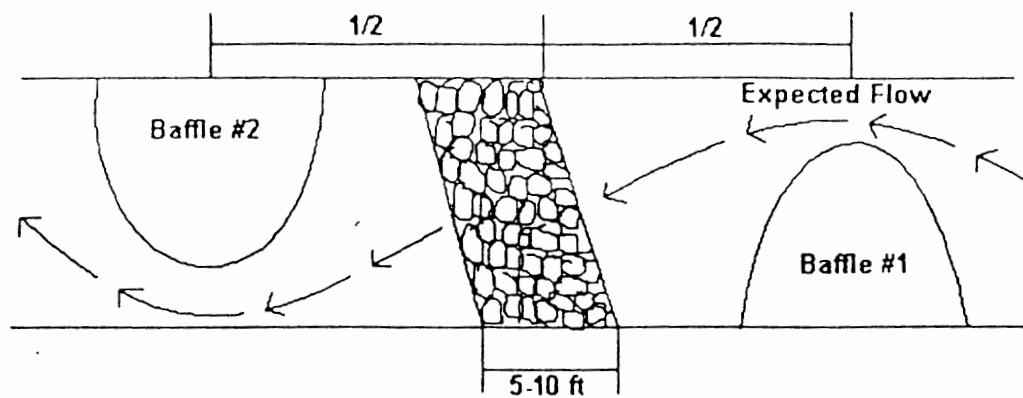
Profile View

Typical baffles are 14 feet at base and extend 12 feet into stream channel unless shown otherwise on plan. Baffles should be 1.5 feet high at base and begin together down at about 6 feet from base.



If channel is less than 4 feet wide from tip bank, dig out a channel at least 4 feet wide and level with bottom of baffle. Remove trees and shrubs.

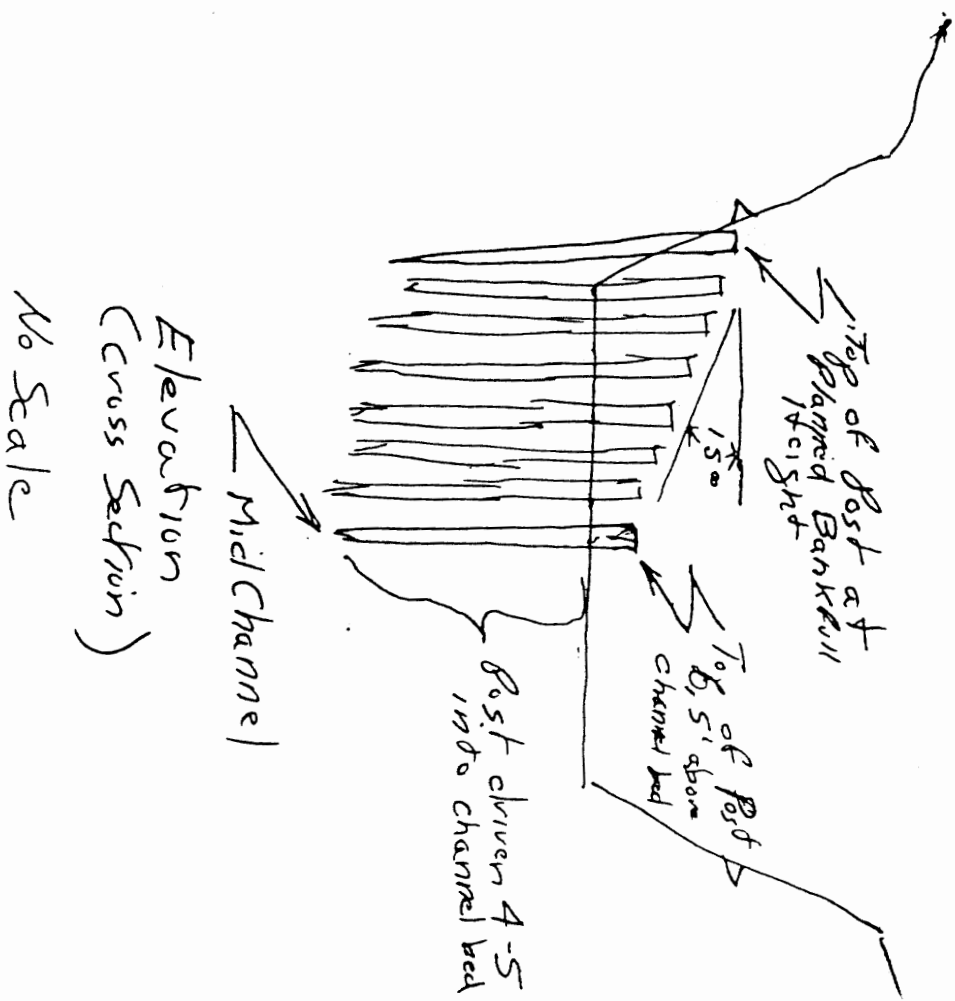
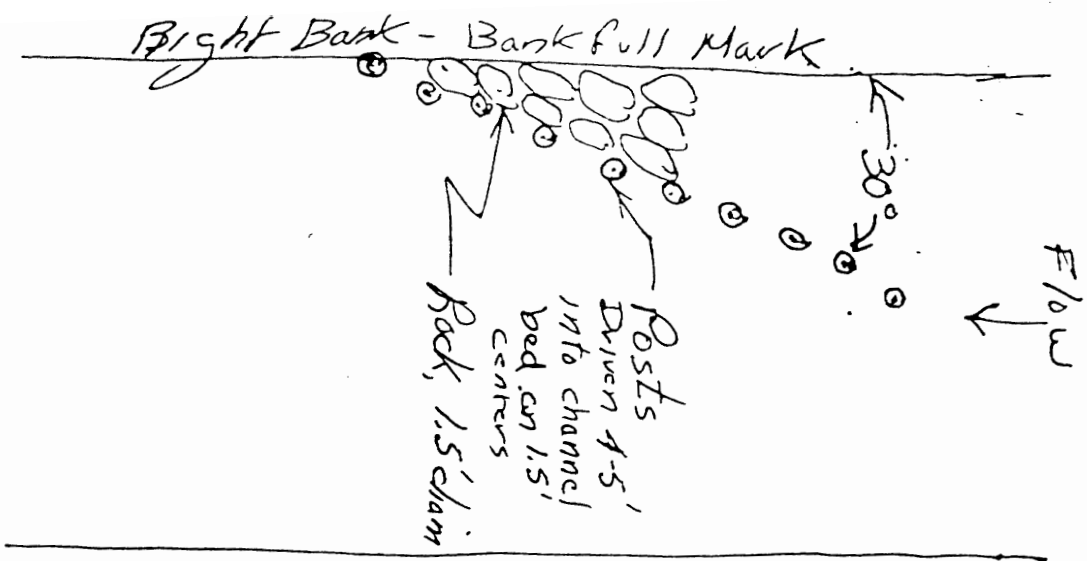
TYPICAL BAFFLE



Typical Riffle

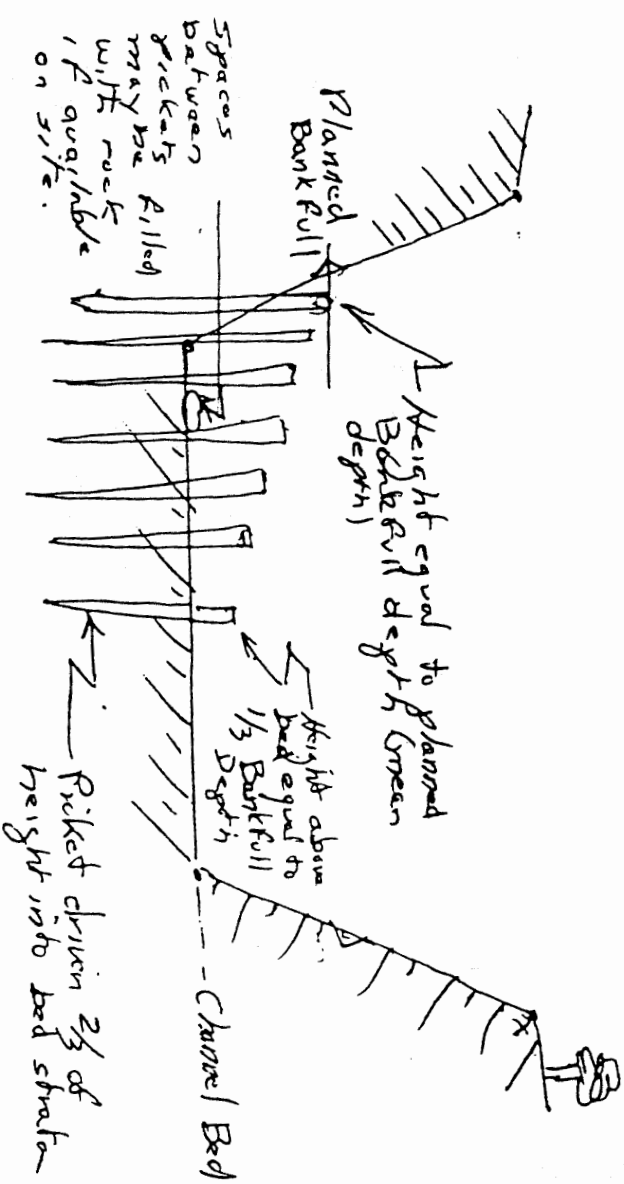
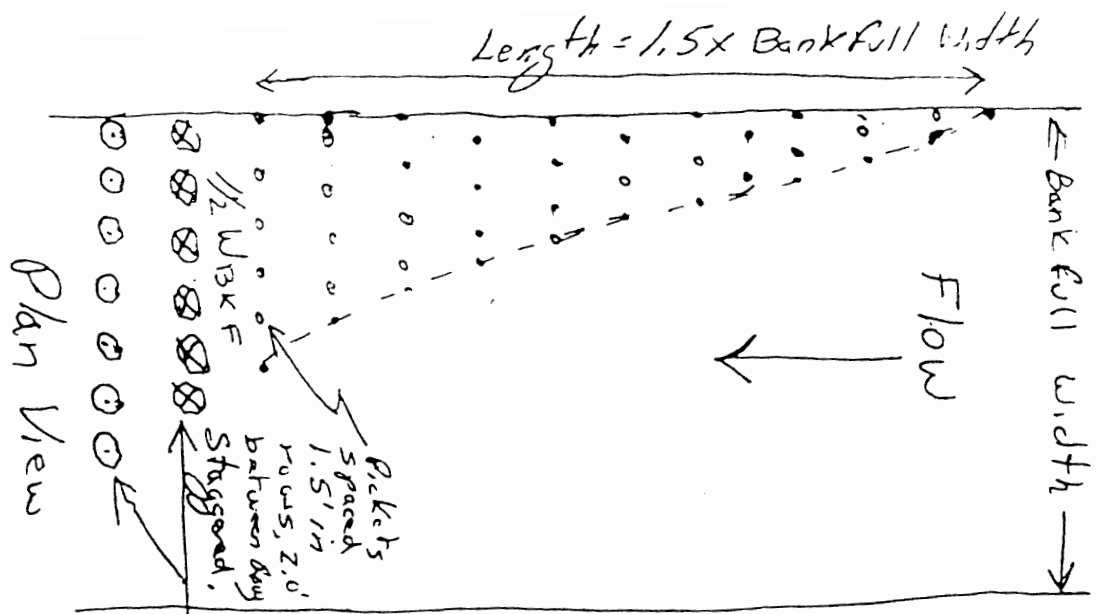
Riffles should be width of stream channel and about 0.5-1.0 feet high.
Build at 70-75 degree angle to stream bank.

Conceptual Drawing: Post Vane
Figure 2



②
B2
2000

Conceptual Drawing: Typical Baffel
Figure 3



Profile View
(Cross Section)

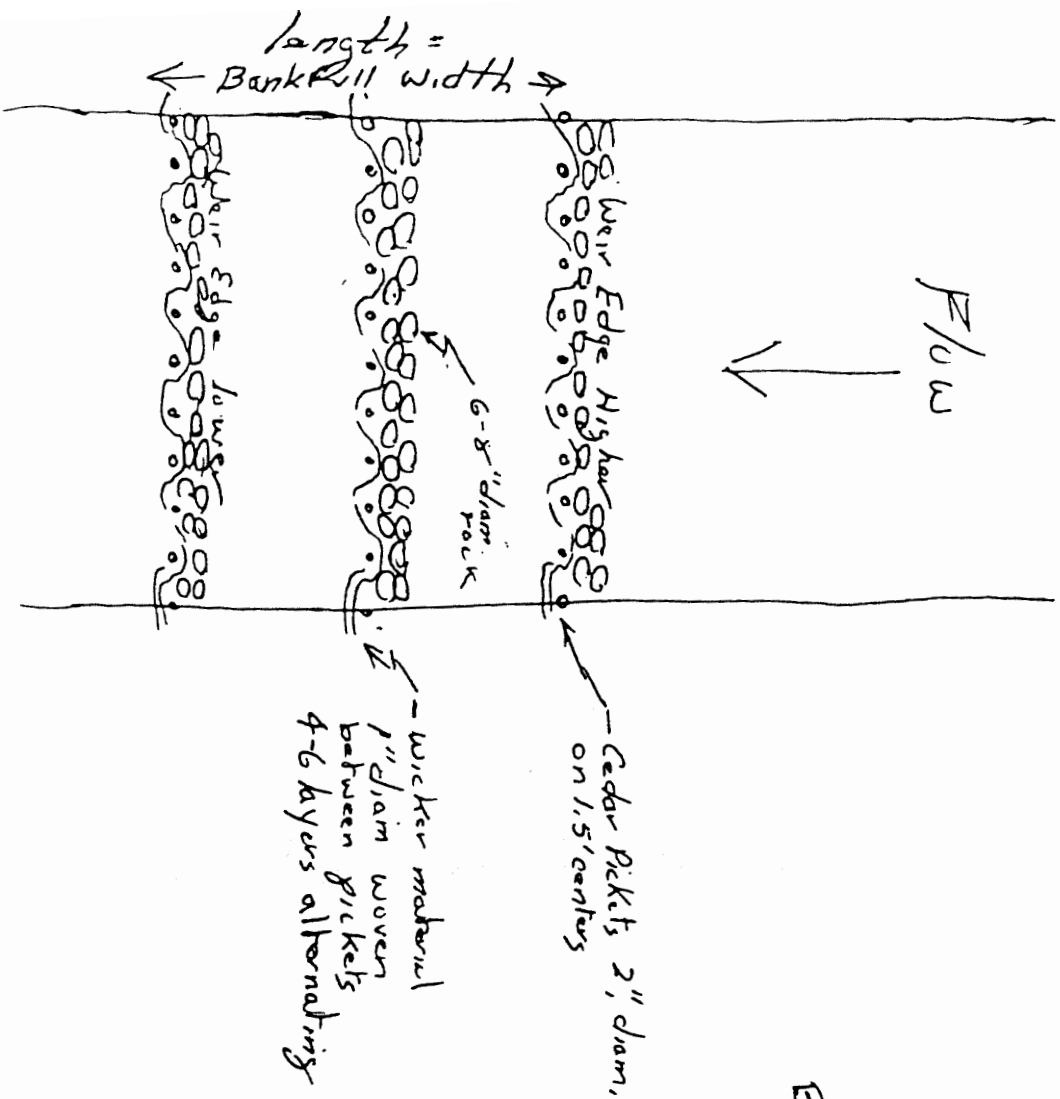
No Scale

Additional pickets
installed as opposite
bank retreats

A-III-5

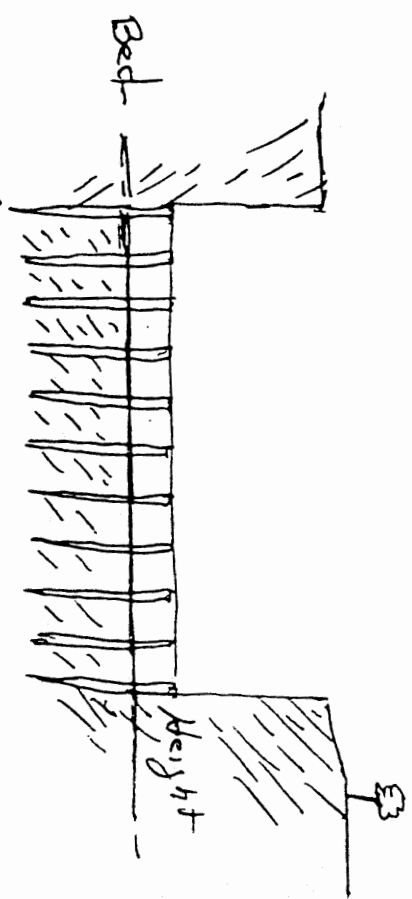
© 2000

Conceptual Drawing: Typical Rifle-Weir
Figure 4



Rifle Weir

A-III-6



Pickets driven $\frac{3}{4}$ their length into stream bed
Height ranges .5-1.0 feet above stream bed elevation depending upon desired gradient of bed slope.
Holes for pickets may be started using unweaving bar or driven without start hole depending upon nature of substrate.
No Scale.

2/2/00

References:

Rosgen, Dave; "Applied River Morphology", 1996, Wildland Hydrology, Pagosa Springs, Colorado

DESCRIPTION OF WATER QUALITY MONITORING ACTIVITIES

Navajo Nation Environmental Protection Agency Water Quality/NPDES staff collected surface water samples from the Pueblo Colorado Wash within the project boundaries. Sample sites varied depending on flow. The project site channel has been perennial for the last three years due to springs. The channel above the project has been intermittent or ephemeral as discussed in the water quantity section. If flow was entering the project from upstream, a sample was collected near the base of the falls and another sample was collected near the downstream end of the project. If no flow was entering from upstream, a sample was taken just downstream of the springs at the top of the project. A second sample was collected as far downstream as was possible as this is a losing stream or the water is infiltrating into the streambed as it moves down the channel. Field data and laboratory analyses for the sampling events are attached in Appendix D.

Comparisons of laboratory analyses were made of the two sample sites to determine if differences in water quality, due to project influence, could be discerned. No significant differences were observed during the three sampling years. The water quality, in general, was good related to the Navajo Nation water quality standards. Designated uses for the Cottonwood Wash, of which Pueblo Colorado Wash is a tributary, are Secondary Human Contact, Ephemeral Warm Water Habitat, and Livestock and Wildlife Watering. The water quality within the project boundaries met the standards at each sampling event except for turbidity which has a NTU standard of 50.

Turbidity, due to suspended sediments, may never be fully mitigated by the project reach. Even with optimum riparian vegetation, the watershed upstream of the project delivers flows heavily laden with suspended sediments during rain and snowmelt runoff events. The project has experienced three storm events, reported in the water quantity section, which heavily impacted riparian vegetation that had been hand planted or was proliferating naturally. *Eleocharis* (Spike-rush), *Juncus* (Rush), and *Scirpus* (Bulrush) species have responded well to protection from livestock and have performed well in trapping sediments to build point bars. The resiliency of these species to sediment inundation is natural and critical to channel stability and function related to water purification. The plants provide a substrate on which algae, bacteria, and other organisms which filter the water live. *Salix* (Willow) and *Populus* (Cottonwood) species also contribute to channel stability and water quality enhancement and are increasing in densities within the project.

Chemical families or analytes not found in the samples at or above the reporting limits were as follows:

- Organochlorine Pesticides
- Polychlorinated Biphenyls
- Chlorinated Herbicides
- Volatile Organics
- Semi-Volatile Organics
- Chemical Oxygen Demand

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE MONITORING ACTIVITIES

The water quality within the project, except for turbidity, met the Navajo Nation water quality standards during the grant period. No significant differences in water quality were observed between upstream and downstream sample points. Future water quality is expected to remain acceptable except for turbidity. Turbidity will be an ongoing problem until upper watershed rehabilitation and management can be accomplished.

Farm irrigation upstream of the project began on a small scale during 2000. Expanded irrigation is expected during the 2001 growing season. Little, if any, fertilizers or pesticides are used on these fields. There are no return flow channels from these fields. Any return to the Pueblo Colorado Wash will be in the form of seeps and springs. It is not anticipated that water quality impairment from fertilizers or pesticides will be a problem. Sediments from farming related erosion are expected to contribute to the overall sediment load in the wash.

Riparian vegetation within the project area is a vital component of overall channel stability and water purification. Livestock have been excluded from the project area and natural expansion and hand plantings will continue. Floodplains are evolving that will help allow flood flows to be dispersed thereby lessening impacts to streambanks and vegetation.

This Program recommends continued water quality monitoring within the project area. Increased vegetation will increase the shading effect. Water temperatures are expected to lower relative to the past three years. Successful watershed planning and rehabilitation projects will reduce sediment loads to the project area and allow the ecosystem to stabilize and function properly.

APPENDIX D:

WATER QUALITY DATA

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APPENDIX D:

WATER QUALITY DATA

ANALYTE	NAVAJO WATER QUALITY STANDARD	1998 RESULTS	1999 RESULTS	2000 RESULTS
TEMPERATURE (C)	32.2 max	27.9	22.2	17.3
PH	6.5-9.0	8.2	8.49	8.1
DO mg/L	5.0 min	6.4	6.9	7.2
TURBIDITY (NTU)	50 max	10	169	21
SPECIFIC CONDUCTIVITY (us/cm)	NO CURRENT NUMERIC STANDARD (NCNS)	760	737	1028
TOTAL DISSOLVED SOLIDS	NCNS	365	362	NOT SAMPLED FOR (NS)
AMMONIA-N	3.0-4.9	NON DETECT (ND)	ND	ND
NITRATE-N	NCNS	0.14mg/L	74.5mg/L	0.096mg/L
PHOSPHORUS	NCNS	0.02mg/L	4.87mg/L	0.057mg/L
ARSENIC	NCNS	NS	ND	NS
BARIUM	NCNS	0.40mg/L	0.913mg/L	NS
CHROMIUM VI	11ug/L	ND	ND	NS
COPPER	500ug/L	ND	ND	NS
LEAD	100ug/L	ND	ND	NS
MERCURY	0.012ug/L	ND	ND	NS
SELENIUM	2ug/L	ND	ND	NS
SILVER	NCNS	ND	ND	NS
ZINC	25mg/L	ND	ND	NS

* Field Data shows only Turbidity field tested for on 07/11/00. Field instruments for pH, DO, SC, TDS, and Temperature were not working properly.

* Laboratories were changed due to labs either going out of business or performance problems.

Hubbell Water Quality Data 2000

<i>SAMPLENAME</i>	<i>SAMPDATE</i>	<i>ANALYTE</i>	<i>RESULT</i>	<i>DL</i>	<i>RL</i>	<i>UNITS</i>
Pueblo Colorado	07/11/2000	Ammonia-N	ND	0.074	0.50	mg/l
Pueblo Colorado	07/11/2000	Nitrate-N	ND	0.020	0.10	mg/l
Pueblo Colorado	07/11/2000	Orthophosphate	ND	0.055	0.50	mg/l
Pueblo Colorado	07/11/2000	Phosphorus	0.057	0.0062	0.050	mg/l
Pueblo Colorado	07/11/2000	Total Suspended Solids	14	10	10	mg/l

Pueblo Colorado Wash Navajo EPA Water Quality Field Data

Site ID 18PUEBLOCO01

SamDate	SamTime	W Temp (C)	pH-Fld	DO (mg/L)	Turbidity (NTU)	SC-Fld (us/cm)	TDS-Fld (mg/L)	Flow (cfs)
09/01/1998	1440	19.2	7.85	6.5	3.32	663	319	
07/19/1999	1355	27.9	8.49	6.2	107	781	383	0.34

Site ID 18PUEBLOCO02

SamDate	SamTime	W Temp (C)	pH-Fld	DO (mg/L)	Turbidity (NTU)	SC-Fld (us/cm)	TDS-Fld (mg/L)	Flow (cfs)
09/01/1998	1525	27.9	8.2	6.4	10	760	365	
07/19/1999	1100	22.2	8.49	6.9	169	737	362	
07/11/2000					18.2			
09/06/2000	0915	17.3	8.1	7.2	21	1028		

WATER QUALITY REPORT

Client: Navajo Nation EPA

Project: Water Quality

Sample ID: HRS1

Lab ID: 0398W05066

Matrix: Water

Condition: Intact

Report Date: 09/30/98

Receipt Date: 09/03/98

Sample Date: 09/01/98

Parameter	Concentration	PQL	Method
GENERAL PARAMETERS			
PH ✓	7.7 s.u.	0.1 s.u.	EPA 150.1
Solids-Total ✓	418 mg/L	10 mg/L	EPA 160.3
Solids - Total Dissolved ✓	340 mg/L	10 mg/L	EPA 160.1
Oxygen Demand - BOD ✓	12 mg/L	2 mg/L	EPA 405.1
Phosphorus - Total ✓	0.3 mg/L	0.02 mg/L	EPA 365.3
Phosphorus - Ortho-P ✓	<0.02 mg/L	0.02 mg/L	EPA 365.3
Nitrogen - TKN ✓	0.4 mg/L	0.1 mg/L	EPA 351.3
Nitrogen - Ammonia ✓	<0.05 mg/L	0.05 mg/L	EPA 350.1
Hardness (CaCO ₃) ✓	276 mg/L	1 mg/L	EPA 130.2
Alkalinity (CaCO ₃) ✓	201 mg/L	1 mg/L	EPA 310.1
Bicarbonate (HCO ₃) ✓	245 mg/L	1 mg/L	EPA 310.1
Carbonate (CO ₃) ✓	<1 mg/L	1 mg/L	EPA 310.1
Hydroxide (OH) ✓	<1 mg/L	1 mg/L	EPA 310.1

MAJOR CATIONS

Calcium ✓	93.4 mg/L	0.2 mg/L	EPA 200.7
Magnesium ✓	10.3 mg/L	0.2 mg/L	EPA 200.7
Sodium ✓	38.3 mg/L	0.2 mg/L	EPA 200.7

MAJOR ANIONS

Chloride ✓	69 mg/L	1 mg/L	EPA 300.0
Fluoride ✓	0.17 mg/L	0.05 mg/L	EPA 340.2
Nitrogen - Nitrate ✓	0.43 mg/L	0.05 mg/L	EPA 353.2
Nitrogen - Nitrite ✓	<0.05 mg/L	0.05 mg/L	EPA 353.2
Sulfate ✓	33 mg/L	5 mg/L	EPA 300.0

Reference EPA - "Methods for Chemical Analysis of Water and Wastes (MCAWW)" - EPA/600/4-79-020 - March, 1983.
 EPA - "Methods for the Determination of Metals in Environmental Samples" - Supplement I - 600/R 94-111 - May, 1994

Reviewed By: 

WATER QUALITY REPORT

Client: Navajo Nation EPA

Project: Water Quality

Sample ID: HRS1

Lab ID: 0398W05066

Matrix: Water

Condition: Intact

Report Date: 09/30/98

Receipt Date: 09/03/98

Sample Date: 09/01/98

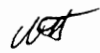
Parameter	Concentration	PQL	Method
BALANCE			
Anion Sum	6.72 meq/L	N/A	N/A
Cation Sum	7.18 meq/L	N/A	N/A
Cation/Anion Balance	3.31 %	N/A	N/A

TOTAL METALS			
Arsenic ✓	<0.005 mg/L	0.005 mg/L	SM 3114B
Barium ✓	0.28 mg/L	0.01 mg/L	EPA 200.7
Chromium ✓	<0.01 mg/L	0.01 mg/L	EPA 200.7
Copper ✓	<0.01 mg/L	0.01 mg/L	EPA 200.7
Iron ✓	0.04 mg/L	0.02 mg/L	EPA 200.7
Lead ✓	<0.005 mg/L	0.005 mg/L	EPA 200.9
Manganese ✓	0.040 mg/L	0.005 mg/L	EPA 200.7
Mercury ✓	<0.001 mg/L	0.001 mg/L	SW-846 7471
Selenium ✓	<0.005 mg/L	0.005 mg/L	SM 3114B
Silver ✓	<0.01 mg/L	0.01 mg/L	EPA 200.7
Zinc ✓	<0.025 mg/L	0.025 mg/L	EPA 200.7

Reference: SM - "Standard Methods for the Examination of Water and Wastewater", APHA-AWWA-WEF, 19th Edition, 1995

EPA - "Methods for the Determination of Metals in Environmental Samples" - Supplement I - 600/R-94-111 - May, 1994

SW-846 - "Test Methods for Evaluating Solid Waste: Physical/Chemical Methods", United States Environmental Protection Agency, Final Update 1 - July 1992.

Reviewed By: 

WATER QUALITY REPORT

Client: Navajo Nation EPA

Project: Water Quality

Sample ID: HRS2

Lab ID: 0398W05067

Matrix: Water

Condition: Intact

Report Date: 09/30/98

Receipt Date: 09/03/98

Sample Date: 09/01/98

Parameter	Concentration	PQL	Method
GENERAL PARAMETERS			
PH ✓	8.3 s.u.	0.1 s.u.	EPA 150.1
Solids-Total ✓	500 mg/L	10 mg/L	EPA 160.3
Solids - Total Dissolved ✓	462 mg/L	10 mg/L	EPA 160.1
Oxygen Demand - BOD ✓	15 mg/L	2 mg/L	EPA 405.1
Phosphorus - Total ✓	0.02 mg/L	0.02 mg/L	EPA 365.3
Phosphorus - Ortho-P ✓	<0.02 mg/L	0.02 mg/L	EPA 365.3
Nitrogen - TKN ✓	0.5 mg/L	0.1 mg/L	EPA 351.3
Nitrogen - Ammonia ✓	<0.05 mg/L	0.05 mg/L	EPA 350.1
Hardness (CaCO ₃) ✓	259 mg/L	1 mg/L	EPA 130.2
Alkalinity (CaCO ₃) ✓	162 mg/L	1 mg/L	EPA 310.1
Bicarbonate (HCO ₃) ✓	194 mg/L	1 mg/L	EPA 310.1
Carbonate (CO ₃) ✓	2 mg/L	1 mg/L	EPA 310.1
Hydroxide (OH) ✓	<1 mg/L	1 mg/L	EPA 310.1

MAJOR CATIONS

Calcium ✓	79.7 mg/L	0.2 mg/L	EPA 200.7
Magnesium ✓	14.4 mg/L	0.2 mg/L	EPA 200.7
Sodium ✓	60.2 mg/L	0.2 mg/L	EPA 200.7

MAJOR ANIONS

Chloride ✓	120 mg/L	1 mg/L	EPA 300.0
Fluoride ✓	0.25 mg/L	0.05 mg/L	EPA 340.2
Nitrogen - Nitrate ✓	0.14 mg/L	0.05 mg/L	EPA 353.2
Nitrogen - Nitrite ✓	<0.05 mg/L	0.05 mg/L	EPA 353.2
Sulfate ✓	53 mg/L	5 mg/L	EPA 300.0

Reference EPA - "Methods for Chemical Analysis of Water and Wastes (MCAWW)" - EPA/600/4-79-020 - March, 1983
 EPA - "Methods for the Determination of Metals in Environmental Samples" - Supplement I - 600/R-94-111 - May, 1994

Reviewed By: _____



WATER QUALITY REPORT

Client: Navajo Nation EPA

Project: Water Quality

Sample ID: HRS2

Lab ID: 0398W05067

Matrix: Water

Condition: Intact

Report Date: 09/30/98

Receipt Date: 09/03/98

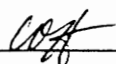
Sample Date: 09/01/98

Parameter	Concentration	PQL	Method
BALANCE			
Anion Sum	7.73 meq/L	N/A	N/A
Cation Sum	7.79 meq/L	N/A	N/A
Cation/Anion Balance	0.390 %	N/A	N/A

TOTAL METALS				
Arsenic	✓	<0.005 mg/L	0.005 mg/L	SM 3114B
Barium	✓	0.40 mg/L	0.01 mg/L	EPA 200.7
Chromium	✓	<0.01 mg/L	0.01 mg/L	EPA 200.7
Copper	✓	<0.01 mg/L	0.01 mg/L	EPA 200.7
Iron	✓	0.07 mg/L	0.02 mg/L	EPA 200.7
Lead	✓	<0.005 mg/L	0.005 mg/L	EPA 200.9
Manganese	✓	0.058 mg/L	0.005 mg/L	EPA 200.7
Mercury	✓	<0.001 mg/L	0.001 mg/L	SW-846 7471
Selenium	✓	<0.005 mg/L	0.005 mg/L	SM 3114B
Silver	✓	<0.01 mg/L	0.01 mg/L	EPA 200.7
Zinc	✓	<0.025 mg/L	0.025 mg/L	EPA 200.7

Reference: SM - "Standard Methods for the Examination of Water and Wastewater", APHA-AWWA-WEF, 19th Edition, 1995
EPA - "Methods for the Determination of Metals in Environmental Samples" - Supplement I - 600/R-94-111 - May, 1994
SW-846 - "Test Methods for Evaluating Solid Waste: Physical/Chemical Methods", United States Environmental Protection Agency, Final Update 1, July 1992.

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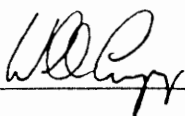
2506 West Main Street, Farmington, NM 87401

Client: Navajo Nation EPA
Project: Water Quality
Sample ID: HRS1
Lab ID: 0399W03658
Matrix: Water
Condition: Cool/Intact

Date Received: 07/21/99
Date Reported: 08/06/99
Date Sampled: 07/19/99
Time Sampled: 1410

Parameter	Analytical		Analysis						
	Result	Units	Units	PQL	Method	Date	Time	Init.	
GENERAL PARAMETERS									
Solids - Total Dissolved	470	mg/L		10	EPA 160.1	07/23/99	1445	TC	
Nitrogen - Ammonia	<0.05	mg/L		0.05	EPA 350.1	08/03/99	1540	WL	
Phosphorus - Ortho-P	<0.02	mg/L		0.02	EPA 365.3	07/21/99	1100	BJ	
Nitrogen - Nitrate	<0.05	mg/L		0.05	EPA 353.2	08/04/99	1410	WL	
Phosphorus - Total	<0.02	mg/L		0.02	EPA 365.3	07/22/99	1020	TC	
Hardness (CaCO3)	210	mg/L		0.2	Calculation	08/04/99	1000	BJ	
Alkalinity (CaCO3)	181	mg/L		1	EPA 310.1	07/28/99	1100	TC	
MAJOR ANIONS									
Bicarbonate (HCO3)	220	mg/L	3.61	meq/L	1	EPA 310.1	07/28/99	1100	TC
Carbonate (CO3)	<1	mg/L	<0.01	meq/L	1	EPA 310.1	07/28/99	1100	TC
Chloride	119	mg/L	3.36	meq/L	1	EPA 300.0	08/02/99	0745	BJ
Fluoride	0.12	mg/L	0.01	meq/L	0.05	EPA 340.2	07/30/99	1103	RV
Hydroxide (OH)	<1	mg/L	<0.01	meq/L	1	EPA 310.1	07/28/99	1100	TC
Sulfate	64	mg/L	1.33	meq/L	5	EPA 300.0	08/02/99	0745	EJ
MAJOR CATIONS									
Calcium	62.9	mg/L	3.14	meq/L	0.2	EPA 200.7	07/29/99	1804	WL
Magnesium	12.9	mg/L	1.06	meq/L	0.2	EPA 200.7	07/29/99	1804	WL
Sodium	75.2	mg/L	3.27	meq/L	0.2	EPA 200.7	07/29/99	1804	WL

Reference: EPA - "Methods for Chemical Analysis of Water and Wastes (MCAWW)" - EPA/600/4-79-020 - March, 1983.
EPA - "Methods for the Determination of Metals in Environmental Samples" - Supplement I - 600/R-94-111 - May, 1994.

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2506 West Main Street, Farmington, NM 87401

Client: Navajo Nation EPA

Project: Water Quality

Sample ID: HRS1

Lab ID: 0399W03658

Matrix: Water

Condition: Cool/Intact

Date Received: 07/21/99

Date Reported: 08/06/99

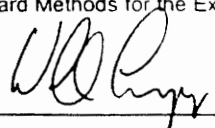
Date Sampled: 07/19/99

Time Sampled: 1410

Parameter	Analytical		Units	PQL	Method	Analysis		
	Result	Units				Date	Time	Init.
DISSOLVED METALS								
Antimony	<0.005	mg/L		0.005	EPA 200.9	07/22/99	1225	SW
Arsenic	<0.005	mg/L		0.005	SM 3114B	07/27/99	0920	HR
Beryllium	<0.002	mg/L		0.002	EPA 200.7	07/29/99	1804	WL
Cadmium	<0.001	mg/L		0.001	EPA 200.9	07/28/99	1035	SW
Chromium	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1804	WL
Cobalt	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1804	WL
Copper	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1804	WL
Lead	<0.005	mg/L		0.005	EPA 200.9	07/29/99	0920	SW
Molybdenum	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1804	WL
Silver	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1804	WL
Thallium	<0.002	mg/L		0.002	EPA 200.9	07/27/99	1000	SW
Vanadium	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1804	WL
Zinc	<0.025	mg/L		0.025	EPA 200.7	07/29/99	1804	WL
TOTAL METALS								
Mercury	<0.001	mg/L		0.001	EPA 245.2	07/30/99	1400	HR
Selenium	<0.005	mg/L		0.005	SM 3114B	07/27/99	1420	EJ

Reference: EPA - "Methods for the Determination of Metals in Environmental Samples" - Supplement I - 600/R-94-111 - May, 1994.

SM - "Standard Methods for the Examination of Water and Wastewater", APHA-AWWA-WEF, 19th Edition, 1995

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Phone (505) 326-4737 Fax (505) 325-4182

2506 West Main Street, Farmington, NM 87401

Client: Navajo Nation EPA

Project: Water Quality

Sample ID: HRS2

Lab ID: 0399W03657

Matrix: Water

Condition: Cool/Intact

Date Received: 07/21/99

Date Reported: 08/06/99

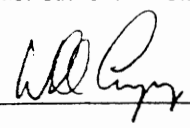
Date Sampled: 07/19/99

Time Sampled: 1130

Parameter	Analytical			Analysis					
	Result	Units		Units	PQL	Method	Date	Time	Init.
GENERAL PARAMETERS									
Solids - Total Dissolved	470	mg/L			10	EPA 160.1	07/23/99	1445	TC
Nitrogen - Ammonia	<0.05	mg/L			0.05	EPA 350.1	08/03/99	1540	WL
Phosphorus - Ortho-P	0.08	mg/L			0.02	EPA 365.3	07/21/99	1100	BJ
Nitrogen - Nitrate	<0.05	mg/L			0.05	EPA 353.2	08/04/99	1410	WL
Phosphorus - Total	0.02	mg/L			0.02	EPA 365.3	07/22/99	1020	TC
Hardness (CaCO3)	216	mg/L			0.2	Calculation	08/04/99	1000	BJ
Alkalinity (CaCO3)	162	mg/L			1	EPA 310.1	07/28/99	1100	TC
MAJOR ANIONS									
Bicarbonate (HCO3)	197	mg/L	3.23	meq/L	1	EPA 310.1	07/28/99	1100	TC
Carbonate (CO3)	<1	mg/L	<0.01	meq/L	1	EPA 310.1	07/28/99	1100	TC
Chloride	111	mg/L	3.12	meq/L	1	EPA 300.0	08/02/99	0745	BJ
Fluoride	0.11	mg/L	0.01	meq/L	0.05	EPA 340.2	07/30/99	1103	RV
Hydroxide (OH)	<1	mg/L	<0.01	meq/L	1	EPA 310.1	07/28/99	1100	TC
Sulfate	58	mg/L	1.21	meq/L	5	EPA 300.0	08/02/99	0745	EJ
MAJOR CATIONS									
Calcium	64.8	mg/L	3.23	meq/L	0.2	EPA 200.7	07/29/99	1801	WL
Magnesium	13.2	mg/L	1.08	meq/L	0.2	EPA 200.7	07/29/99	1801	WL
Sodium	77.9	mg/L	3.39	meq/L	0.2	EPA 200.7	07/29/99	1801	WL

Reference: EPA - "Methods for Chemical Analysis of Water and Wastes (MCAWW)" - EPA/600/4-79-020 - March, 1983.

EPA - "Methods for the Determination of Metals in Environmental Samples" - Supplement I - 600/R-94-111 - May, 1994.

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2506 West Main Street, Farmington, NM 87401

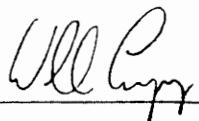
Client: Navajo Nation EPA
Project: Water Quality
Sample ID: HRS2
Lab ID: 0399W03657
Matrix: Water
Condition: Cool/Intact

Date Received: 07/21/99
Date Reported: 08/06/99
Date Sampled: 07/19/99
Time Sampled: 1130

Parameter	Analytical Result	Units	Units	PQL	Method	Analysis		
						Date	Time	Init.
DISSOLVED METALS								
Antimony	<0.005	mg/L		0.005	EPA 200.9	07/22/99	1225	SW
Arsenic	<0.005	mg/L		0.005	SM 3114B	07/27/99	0920	HR
Beryllium	<0.002	mg/L		0.002	EPA 200.7	07/29/99	1801	WL
Cadmium	<0.001	mg/L		0.001	EPA 200.9	07/28/99	1035	SW
Chromium	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1801	WL
Cobalt	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1801	WL
Copper	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1801	WL
Lead	<0.005	mg/L		0.005	EPA 200.9	07/29/99	0920	SW
Molybdenum	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1801	WL
Silver	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1801	WL
Thallium	<0.002	mg/L		0.002	EPA 200.9	07/27/99	1000	SW
Vanadium	<0.01	mg/L		0.01	EPA 200.7	07/29/99	1801	WL
Zinc	0.091	mg/L		0.025	EPA 200.7	07/29/99	1801	WL
TOTAL METALS								
Mercury	<0.001	mg/L		0.001	EPA 245.2	07/30/99	1400	HR
Selenium	<0.005	mg/L		0.005	SM 3114B	07/27/99	1420	EJ

Reference: EPA - "Methods for the Determination of Metals in Environmental Samples" - Supplement I - 600/R-94-111 - May, 1994.
SM - "Standard Methods for the Examination of Water and Wastewater", APHA-AWWA-WEF, 19th Edition, 1995.

Reviewed By:





Navajo Nation P.O. Box 339 Window Rock, AZ 86515 Attention: Eric Rich	Client Project ID: P174449 Report Number: PJG0122	Sampled: 07/11/00 Received: 07/12/00
--	--	---

INORGANICS

Analyte	Method	Batch	Reporting Limit mg/l	Sample Result mg/l	Dilution Factor	Date Extracted	Date Analyzed	Data Qualifiers
Sample ID: PJG0122-01 (Pueblo Colorado HBL (Hubbell) - Water)								
Ammonia-N	EPA 350.3	P0G1924	0.50	ND	1	7/19/00	7/19/00	
Nitrate-N	EPA 300.0	P0G1314	0.10	ND	1	7/12/00	7/12/00	
Orthophosphate	EPA 300.0	P0G1314	0.50	ND	1	7/12/00	7/12/00	L
Phosphorus	EPA 365.3	P0G2025	0.050	0.057	1	7/20/00	7/20/00	
Total Suspended Solids	EPA 160.2	P0G1321	10	14	1	7/13/00	7/14/00	

DEL MAR ANALYTICAL, PHOENIX (AZ0426)

Nicole Beck
Project Manager

PJG0122
Page 2 of 6

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 11501 Sherman Way, Suite 101, Van Nuys, CA 91411 (818) 773-1844 FAX (818) 773-1845
 10284 Chesapeake Dr. Suite 100, San Diego, CA 92121 (619) 594-3540 FAX (619) 594-3541
 10000 San Diego Ave. Suite 100, San Diego, CA 92121 (619) 594-3540 FAX (619) 594-3541

Navajo Nation
 P.O. Box 339
 Window Rock, AZ 86515
 Attention: Eric Rich

Client Project ID: P174449
 Report Number: PJG0122

Sampled: 07/11/00
 Received: 07/12/00

METHOD BLANK/QC DATA

INORGANICS

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Data Qualifiers
Batch: P0G1314 Extracted: 07/12/00										
Blank Analyzed: 07/12/00 (P0G1314-BLK1)										
Nitrate-N	ND	0.10	mg/l							
Orthophosphate	ND	0.50	mg/l							
LCS Analyzed: 07/12/00 (P0G1314-BS1)										
Nitrate-N	89.3		mg/l	0.903		107	90-110			
Orthophosphate	2.41	0.50	mg/l	1.94		124	90-110			L
LCS Dup Analyzed: 07/12/00 (P0G1314-BSD1)										
Nitrate-N	0.907	0.10	mg/l	0.903		100	90-110	5.99	20	
Orthophosphate	2.27	0.50	mg/l	1.94		117	90-110	5.98	20	L
Matrix Spike Analyzed: 07/12/00 (P0G1314-MS1)										
Nitrate-N	89.3	10	mg/l	90.3	5.6	92.7	80-120			
Orthophosphate	220	50	mg/l	194	ND	113	80-120			
Matrix Spike Dup Analyzed: 07/12/00 (P0G1314-MSD1)										
Nitrate-N	87.3	10	mg/l	90.3	5.6	90.5	80-120	2.27	20	
Orthophosphate	235	50	mg/l	194	ND	121	80-120	6.59	20	M2
Batch: P0G1321 Extracted: 07/13/00										
Blank Analyzed: 07/14/00 (P0G1321-BLK1)										
Total Suspended Solids	ND	10	mg/l							
Duplicate Analyzed: 07/14/00 (P0G1321-DUP1)										
Total Suspended Solids	ND	10	mg/l		ND				10	

Source: PJG0099-03

Source: PJG0099-03

Source: PJG0084-01



2810 Alton Ave. Irving CA 92606	(949) 261-1022 FAX (949) 261-1024
1014 E. 1st St. Santa Ana CA 92704	909 370-4667 FAX 909 370-4668
10100 S. Bascom Ave. Suite 100 San Jose CA 95128	818 779-1844 FAX 818 779-1845
4444 S. Bascom Ave. Suite 500 San Jose CA 95128	858 565-9586 FAX 858 565-9587
10000 S. Bascom Ave. Suite 500 San Jose CA 95128	408 755-5555 FAX 408 755-5556

Received: 07/12/00

INORGANICS

Nicole Beck
Project Manager

PJG0122
Page 4 of 6

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Navajo Nation
P.O. Box 339
Window Rock, AZ 86515
Attention: Eric Rich

Client Project ID: P174449

Report Number: PJG0122

Sampled: 07/11/00

Received: 07/12/00

METHOD BLANK/QC DATA

INORGANICS

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	Limits	RPD	RPD Limit	Data Qualifiers
Batch: P0G2025 Extracted: 07/20/00										
Matrix Spike Analyzed: 07/20/00 (P0G2025-MS1)					Source: PJG0122-01					
Phosphorus	0.620	0.050	mg/l	0.500	0.057	113	75-125			
Matrix Spike Dup Analyzed: 07/20/00 (P0G2025-MSD1)					Source: PJG0122-01					
Phosphorus	0.617	0.050	mg/l	0.500	0.057	112	75-125	0.485	20	



Navajo Nation
P.O. Box 339
Window Rock, AZ 86515
Attention: Eric Rich

Client Project ID: P174449

Report Number: PJG0122

Sampled: 07/11/00

Received: 07/12/00

METHOD BLANK/QC DATA

See attached Method Blank Report

DATA QUALIFIERS AND DEFINITIONS

- L** Laboratory Control Sample recovery was above the method control limits. Analyte not detected, data not impacted.
- M2** Matrix Spike recovery was outside the method control limits. See Corrective Action Report.
- ND** Analyte NOT DETECTED at or above the reporting limit
- NR** Not reported.
- RPD** Relative Percent Difference

Chapter 6 - Water Quantity Monitoring